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Review

Pomegranate Wine Production and Quality: A Comprehensive Review

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Abstract: Food and beverages with healthy and functional properties, especially those that prevent chronic diseases, are receiving considerable interest among consumers and researchers. Among the products with enhanced properties, fermented beverages from non-grape wines have a high potential for growth. Pomegranate (*Punica granatum* L.) is a super fruit known for its richness in bioactive compounds that have been reported to have several therapeutic properties against non-communicable diseases. Diverse products can be obtained from the valorization of pomegranate fruit, including wines, supplements, dried arils, juices, vinegar, and syrup. There is no literature evidence of the optimization of the fermentation processes of pomegranate juice that explores the relationships between multiple factors and their interactions. This review provides an overview of the composition of pomegranate fruit and the related health benefits for human health. It also discusses the ways in which pomegranate wine fermentation is impacted by pre-fermentation and fermentation factors. Additionally, it highlights the different subjective and objective techniques for analyzing pomegranate wine quality and the advancement of technologies such as sensors to replace traditional methods of sensory evaluation. It provides comprehensive insights into how different fermentation factors interact and can improve the bioprocess, leading to the production of high-quality wine.

Keywords: *Punica granatum*; fermentation; optimization; yeast; value addition

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1. Introduction

The pomegranate (*Punica granatum* L.) is a short shrub that belongs to the Lythraceae family. The fruit is globose or somewhat flat at the top, weighing between 200 and 650 g or more depending on the cultivar [1]. Most commercial cultivars of pomegranate fruit are usually green in color when unripe but change to red upon fruit ripening (Figure 1). Depending on the cultivar, pomegranate fruit can either be classified as sweet (e.g., Mollar de Elche, Acco, sweet red), sour (Wonderful) or sweet sour (Hershkovitz). The fruit is cultivated throughout the world in Mediterranean, subtropical and tropical climatic conditions [2–5].

The global analysis of pomegranate is made difficult because there is no unique Harmonized Code (HS code) for this fruit. They are grouped with various other fruit under the HS code 081090, called “other fresh fruit-other” [6]. Information on global pomegranate production is gathered through various reports, statistical agencies and producers or export associations. Countries leading in pomegranate production include India, Iran, Turkey, Egypt, USA, Afghan, Azerbaijan, Tunisia, Spain, Peru, Pakistan, Italy, South Africa, and Mexico. The world's pomegranate production is around 8.1 million tons, with a total planted area of 835,950 ha, which is expected to increase yearly [6]. Pomegranate production in these 14 countries increased from 2.5 million tons in 2012 to 8.1 million tons in 2021. Over this time frame, the annual growth rate was 12.6%.

Figure 1. Mature pomegranate fruit on a tree at the Blydeverwacht farm, Wellington, Western Cape, South Africa (Image taken by the author in March 2023).

Globally, India is the world's leading pomegranate producer, surpassing other producing countries in terms of both cultivated area and production, followed by Iran. According to [7], India produces nearly 2.8 million tons of pomegranate on 220,000 ha, making it the world's leading pomegranate producer. Iran is ranked second in world pomegranate production with a total production of 915,000 tons and a cultivation area of 90,000 ha. Despite India and Iran being the two largest producers of pomegranate, respectively, only 7% and 1.5% of the total production are exported. Turkey, Egypt, and India are the world's largest exporters of pomegranate fruit with a total volume of 155,189 tons, 127,447 tons, and 67,891 tons, respectively [6].

In Europe, Spain is the biggest producer and exporter of pomegranate, with a yield of 18.5 tons/ha [7]. In the southern hemisphere, Peru and South Africa are the highest producers of pomegranate, with a total production area of 2935 ha and 963 ha, respectively [8]. Global pomegranate exportation has shown a steady growth, with the exportation rate increasing from 450,000 to 668,000 tons between 2012 and 2019. The global pomegranate market size was valued at USD 248.4 million in 2022 and it is projected to grow at a compound annual growth rate (CAGR) of 5.3% to reach USD 338.6 million in 2030.

Every part of pomegranate fruit, including the bark, leaves, rind, flowers, arils, and peel, contain a high concentration of polyphenolic compounds like ellagitannins, ellagic acids, catechin, epicatechin, and anthocyanins [5,9–11]. The bioactive compounds in pomegranate fruit are known to be ten times higher than those found in red wines, making them an ideal substrate to produce food products rich in bioactive compounds [12]. These bioactive compounds are known to be anti-carcinogenic, anti-diabetic, and anti-inflammatory [13–16].

The pomegranate fruit is made up of three main parts: the peel, arils and kernels. All parts of pomegranate fruit can be processed into value-added products, as shown in Figure 2. The aril is the edible part of the fruit that contains the juice; it can be consumed fresh or dried or be converted to juice, which can further be converted into wine through the process of alcoholic fermentation [17–20]. Pomegranate peels can be used in the pharmaceutical industries as a supplement, in the food and beverage industry as a food additive, and in the production of ink/dye [5]. The kernels of pomegranate fruit are known to be the highest natural source of punicic acid; the kernel is rich in oil, which is used in the cosmetic industries for the formulation of beauty products and in pharmaceutical companies for the formulation of supplements [21].

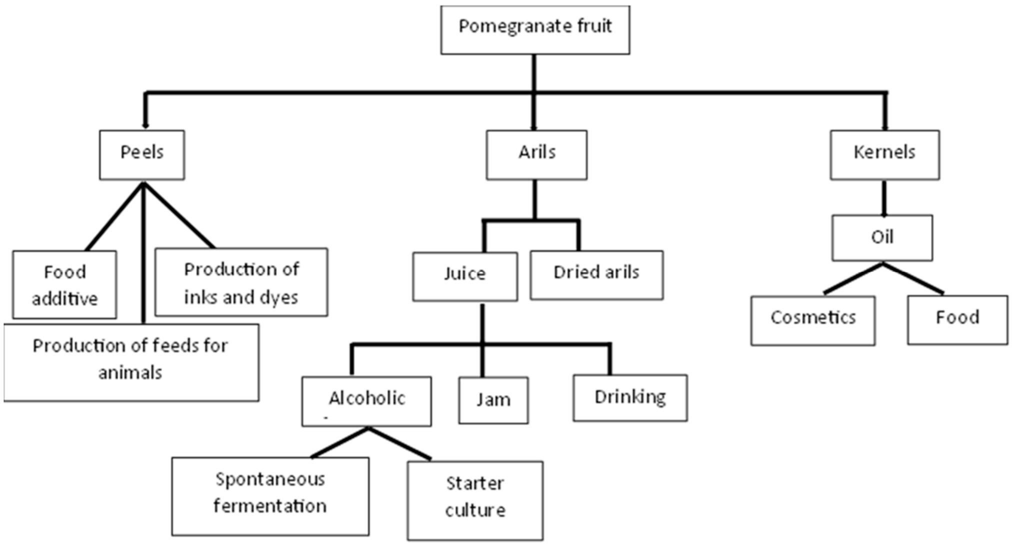

Figure 2. Different value-added products obtained from bioprocessing of pomegranate fruit.

Aside from being consumed in their fresh form, pomegranate arils can also be converted into other value-added products like jam [22,23], juice [18,24–26], and wine [17,27–33]. To produce a good-quality wine from pomegranate fruit, several pre-fermentation and fermentation factors need to be considered. The pre-fermentation factors include selecting the right cultivar, choosing the right juice extraction method, and obtaining the right juice blend in cases where different cultivars with different chemical characteristics are used. In addition to the pre-fermentation factors, the fermentation factor is considered the most critical factor in winemaking as it involves selecting a suitable yeast to carry out fermentation. The choice of yeast used in fermentation can either impart negatively or positively on the flavor and aroma of the final product.

Although wine produced from pomegranate is an existing product, the method still relies heavily on the grape wine production process, and there is no reported study on how the different fermentation factors interact with each other during pomegranate wine production. This review provides an overview of pomegranate fruit composition and discusses fermentation strategies aimed at producing pomegranate fermented beverages. Furthermore, it highlights different techniques for analyzing pomegranate wine quality.

2. Physicochemical and Phytochemical Properties of Pomegranate Fruit Relevant to Winemaking

The chemical composition of pomegranate fruit differs depending on the cultivar, maturity, cultivation practice, climate, and storage conditions [34]. The longitudinal section of the fruit, as seen in Figure 3, exposes the edible arils, the membrane, and the albedo. The epicarp/peel accounts for about 49 to 55% of the weight of the fruit depending on the cultivar [35]. The arils, which are the edible part of the fruit, account for about 45–52% of the weight of the whole fruit [5] and are filled with juicy pulp. The extraction of the juice from the arils leaves several small kernels containing oil, which has been reported to have many therapeutic properties, and this accounts for about for about 12–20% of the fruit weight [35].

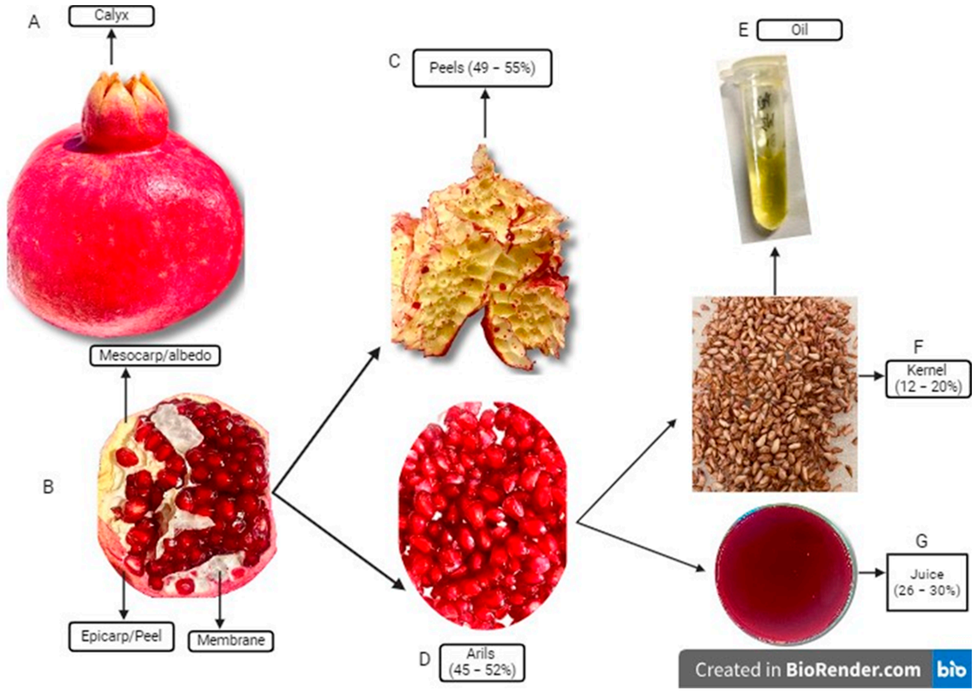

Figure 3. Sections of *Punica granatum* L. fruit. (**A**) Whole fruit; (**B**) Longitudinal section of pomegranate fruit; (**C**) Epicarp/Peel; (**D**) Arils; (**E**) Oil; (**F**) Kernel/seed; (**G**) Juice.

Pomegranate is considered a superfruit because of its relatively rich antioxidant properties, bioactive compounds, and therapeutic properties [10,34]. Since ancient times, people have known about pomegranate—a fruit with a variety of biological benefits for health that are mostly related to its phenolic content, primarily anthocyanins and ellagitannins [34,35]. A considerable fraction of organic acids, soluble solids, and nutritionally important minerals can be found in pomegranate fruit (Tables 1 and 2). Due to growing consumer awareness of "superfruits", the juice/beverage and functional food industries have swiftly progressed in the development of various products containing pomegranates [36].

Table 1. Average chemical composition of a mature pomegranate fruit across different cultivars.

Constituent	Concentration	References
Total sugar (mg/100 L)	1288.07 ± 21.32	[37]
Total organic acids	188.07 ± 8.74	[37]
Total phenolic content (mg GAE/L)	2470.1 ± 14.8	[32]
Total antioxidant content (μM TE/g)	184.25	[38]
Total flavonoid content (mg/L)	320.2 ± 4.5	[32]
Total anthocyanin content (mgC3gE/100 mL PJ)	32.11	[38]
Water content (%)	74.92	[37]
Ash content (%)	2.20	[37]
Vitamin C (μg AAE/mL)	114.33	[38]

Table 2. Mineral composition of pomegranate fruit [9].

Mineral (Major)	Aril (mg/100 g)	Rind (mg/100 g)	Mesocarp (mg/100 g)
N	350.57	207.93	167.14
P	53.60	22.28	20.42
K	222.86	401.14	305.64
Ca	15.44	30.81	15.86
Mg	20.14	14.56	7.77
S	20.92	12.10	8.97
Cl	31.82	65.92	37.92
Na	23.66	58.44	31.29
Mineral (Trace)			
Mn	1.70	1.64	0.68
Fe	5.85	2.32	1.70
Cu	1.71	0.77	1.09
Zn	4.17	2.31	1.65
B	3.49	4.19	5.01
Ni	0.31	0.81	1.05
Co	-	0.03	0.05
Cr	0.43	0.76	0.97
Li	0.21	0.29	0.21
Pb	0.47	0.34	0.32
Cd	0.03	0.03	0.40
Se	3.08	2.84	2.20
Ai	-	8.52	7.34
As	-	0.23	0.52
Sr	1.90	12.51	5.44
Ti	0.01	-	0.01
V	0.10	0.01	0.004

The mineral content of fruits and vegetables adds to their nutritional value. For healthy growth, function, and general health, humans need different amounts of mineral elements [39]. The two major categories of mineral nutrients are major and trace elements. While the main elements (Ca, P, Mg, S, K, Cl, Na) make up 1% of body weight and are needed in doses more than 100 mg per day, trace minerals (Zn, Fe, Mn, Cu, Si, Fl, I, Cr) make up less than 0.01% of body weight and are required in considerably smaller doses [39]. According to research by [9], the mineral elements contained in pomegranate arils fulfill the dietary recommended daily allowances (RDA), showing that pomegranate arils are a healthy source of minerals for consumers.

The functional properties found in pomegranate fruit are dominated by phenolic compounds. These compounds range from simple molecules (phenolic acids, flavonoids, phenylpropanoids) to highly polymerized compounds (lignins, melanins, tannins) [35]. The biological activity exhibited by pomegranate fruit is as a result of the diverse secondary metabolites found in different parts (bark, seed, aril, oil, flower, juice) of the fruit, as shown in Table 3. Various scientific studies have shown that the distribution and concentration of these chemical compounds are influenced by cultivar, growing environment, climate, fruit processing and fruit maturity [25,37,40,41].

Numerous other studies performed over the years have shown that pomegranate extracts possess a wide range of pharmacological properties such as antimicrobial [42], anti-inflammatory [43], cardioprotective [44], free radical scavenging [3,37], hepatoprotective [45], tyrosinase inhibition property [37] and anti-diabetic effects [46].

Table 3. Phytochemical constituents of different parts of pomegranate plant.

Plant Part	Constituents	References
Peel	Ellagitannins, gallic acid, catechin, epicatechin, quercetin, rutin, flavones, flavonols, proanthocyanins, anthocyanins, caffeic acid, p-coumaric acid, punicalagin, protocatechuic acid, vanillic acid, quercetin, coumarin.	[18,47]
Flower	Gallic acid, ellagic acid, punicalagin, punicalins, anthocyanins.	[14]
Leaf	Punicafolin, punicalin, luteolin, apigenin.	[18]
Juice	Catechin, epicatechin, gallic acid, protocatechuic acid, rutin, ellagic acid, caffeic acid, quercetin, proanthocyanidins, anthocyanins.	[18,40,47,48]
Seed oil	Punicic acid, gallic acid, ellagic acid, sterols.	[5,10,13]
Roots and bark	Ellagitannins, punicalin, punicalagin, luteolin, apigenin, brevifolin carboxylic acid.	[5,10,13,49]

Due to both their chemical makeup and sensory appeal, pomegranate fruits have garnered enormous interest among scientists worldwide. Pomegranate-derived products have very appealing sensory qualities that make them highly desirable for customers in comparison to fresh fruit [11]. Designing foods that are preserved via natural processes, such as fermentation, is encouraged, due to customers' growing concern over artificial preservatives.

3. Pomegranate Fruit as a Wine Substrate

The edible part of pomegranate fruit is made up of 85.4% water and 15.6% dry substances, composed of sugars, organic acids, pectins, anthocyanins, polyphenols, vitamins, and minerals [47]. The seeds, on the other hand, are rich sources of lipids, proteins and punicalagins [21], while the peels and rinds are rich sources of hydrolysable tannins and anthocyanins, which are responsible for the bitter taste and its coloring [5]. The rich medium of pomegranate fruit will provide a suitable environment for yeast growth during pomegranate wine production.

A considerable amount of research has been conducted on pomegranate wine using different fruit cultivars and fermentation conditions (Table 4). Lan et al. [30] produced wine from pomegranate juice using the Bright red cultivar. The sugar content of the extracted pomegranate juice was adjusted to 20 °Brix, and fermentation was carried out at a temperature of 28 °C for 16 days. The wine was aged for 10 days, and changes in the antioxidant activity, phenolic contents, organic acid and flavor characteristics were investigated. The DPPH scavenging capacity changed during the fermentation and aging process. Despite the small loss, the produced pomegranate wine retained a substantial capacity to inhibit DPPH reduction. Changes were also observed in the phenolic compounds during pomegranate wine fermentation, and the author attributed this to be as a result of the degradation and yeast activity and/or other oxidative mechanisms throughout the winemaking process.

Zhuang et al. [27] studied the changes in the antioxidant capacity of pomegranate wine produced using three (sour, sweet and red) different cultivars. The concentration of the total phenolics and antioxidant capacity varied between cultivars. The total phenolics in the sweet, sour, and red pomegranate were 1596.67, 932.83 and 1096.61 mg/L, respectively. In terms of the chemical analysis, the sugar depletion during fermentation was higher in wines produced from the sour pomegranate compared to the sweet and red pomegranates. Furthermore, the different cultivars used produced different concentrations of alcohol ranging from 12.16 to 14.11%, with the highest alcohol production found in the sweet pomegranate cultivar.

Several other published studies have shown that pomegranate juice provides a suitable medium for yeast growth during pomegranate juice fermentation [30,32,33,50]. Even though the production process of pomegranate wine still relies on the process developed for grape wine, the compositions of pomegranate and grape differ in their physiochemical, phytochemical, and antioxidant activities and even their microflora. Therefore, it would be necessary to optimize and understand the interactions between these fermentation conditions, including the pH, temperature, and inoculum size, and how these interactions would be suitable for pomegranate wine production.

Table 4. Examples of some published studies on pomegranate wine.

Cultivar	Location	Fermentation Conditions	Measured Parameters	Research Findings	Reference
Bright red sweet	China	Temperature 28 °C, TSS 20 °Brix, Inoculum size 1 g/L, Aging 10 days, Active dry yeast	pH, TA, TSS, Alcohol, Organic acid, TPC, TAC, DPPH, Super oxide anion and hydroxyl radicals scavenging activity, Phenolic compounds, E-nose analysis, E-tongue analysis, VA	Despite little loss of polyphenols and antioxidant compounds during fermentation and aging, pomegranate wine still contained high amount of phenolic compounds, flavor properties and great antioxidants capable of scavenging free radicals.	[30]

Table 4. *Cont.*

Cultivar	Location	Fermentation Conditions	Measured Parameters	Research Findings	Reference
Sweet Qingpi, Sour Qingpi, Red Mountain Tai	China	Temperature 20–22 °C *Saccharomyces cerevisiae*	pH, TA, sugar, alcohol, color, glycerol, TP, TA, DPPH, FRAP, OH, O^{2-}	The concentration of phenolic compounds and antioxidant activities present in pomegranate wine differed according to the fruit cultivars investigated. Sweet cultivar had the highest (1596.67 mg/L) total phenolic content, the lowest (932.83 mg/L) phenolic compound was found in the sour cultivar.	[27]
Not stated	China	*Saccharomyces cerevisiae*, Duration 8 days, Temperature 22 °C, Stabilization 17 days (10 °C)	pH, TSS, ethanol	Several diverse native fungi were found in pomegranate juice using high throughput sequencing and the inoculation of *Saccharomyces cerevisiae* decreased granger casualties between native yeasts and volatile organic compounds.	[51]
Jingpitian	China	Not stated	Polyphenols, antioxidants		[52]
Wonderful	Greece	Temperature 15 °C and 25 °C, *Saccharomyces bayanus*, *Saccharomyces cerevisiae*, *Saccharomyces cerevisiae* var. *diastaticus*,	Reducing sugar, alcohol, glycerol, pH, volatile acidity, total acidity, TFC, TPC, YAN, TAC, antioxidant	The yeast strain and the fermenting temperature affected the wine quality. While the yeast used affected mainly the flavonoids and anthocyanins, the fermentation temperature significantly affected the volatile composition.	[32]

Table 4. *Cont.*

Cultivar	Location	Fermentation Conditions	Measured Parameters	Research Findings	Reference
Kesar	India	Duration 9 days, TSS 24–40 °Brix, Inoculum size 3%, Secondary fermentation 7 days, Aging 90 days, *Saccharomyces cerevisiae var ellipsoideus*	TSS, TA, AAC, Antioxidant	Pomegranate wine produced with 7% rind powder had a better organoleptic characteristic, ascorbic acid (12.77 mg/100 mL), alcohol (13.54%), tannin (71.60 mg/100 mL) and antioxidant contents (1307.60 mg AAE/100 mL) over other wine formulations at the end of 90 days storage.	[53]
Bhagwa, Ganesha	India	Temperature 25 °C, Duration 35 days, *Saccharomyces ellipsoideus*, *Candida stellate* (immobilized)	TA, pH, alcohol	Wines fermented with mixed cultures of *Saccharomyces cerevisiae* and non-*Saccharomyces cerevisiae* yeast species had lower volatile acidity and ethanol concentration compared to a monoculture of *Saccharomyces cerevisiae* yeast	[54]
Not stated	Israel	Temperature RT, Duration 10 days, *Saccharomyces bayanus*,	Antioxidant activity, Polyphenol, cyclooxygenase, lipoxygenase	Pomegranate fermented juice and cold pressed seed oil showed strong antioxidant activity close to butylated hydroxyanisole (BHA) and green tea but were higher than that of red wine.	[55]
Common Molfetta	Italy	Temperature 30 °C, Duration 5 days, Aging (4 °C) 30 days, *Lactobacillus plantarum C2*, *POM1*, *LP09* (7.0 CFU/mL)	pH, TA, color, browning indices, organic acids, carbohydrates, free amino acids, VFA, polyphenols, antioxidant, antimicrobial assay, cell culture and immunoassay, reactive oxygen species	Using lactic acid bacteria as a starter for pomegranate wine fermentation resulted in better physicochemical, phytochemical and antioxidant properties compared to unstarted juice. The starters showed the ability to grow in pomegranate juice as they increased from 7.0 Log CFU/mL to 9.0 Log CFU/mL at the end of fermentation.	[56]

Table 4. *Cont.*

Cultivar	Location	Fermentation Conditions	Measured Parameters	Research Findings	Reference
Jolly red, Smith	Italy	Duration 8 days, Aging 3 months, *Saccharomyces cerevisiae bayanus EC1118*, *Saccharomyces clos*	pH, SO_2, color intensity, total sugar, organic acids, polyphenols, volatile compounds,	Fermentation using different pomegranate fruit cultivars and yeast influenced the fermentation process and differences were observed in the chemical profile which was a function of the interaction between cultivar and the yeast species investigated.	[33]
Wonderful, Mollar de Elche	Spain	Temperature 22 °C, Duration 6 days, Clarification 1 day (4 °C) Stabilization 10 days, *Saccharomyces bayanus*	TA, pH, TSS, Formol index, VA, Alcohol, TPC	Melatonin was found to be absent in pomegranate juice but was detected in pomegranate wines suggesting that this substance is being synthesized during alcoholic fermentation.	[57]
Wonderful	Spain	Temperature 19 °C, Duration 6 days, Racking 4 °C, 1 day, Stabilization 10 days, *Saccharomyces bayanus*	TPC, DPPH, ABTS+, mineral content,	Pomegranate wine lees proved to be a potential source for nutraceutical supplement with high phenolic content (about 30 mg GAE/g dry matter) and antioxidant capacity.	[58]
Wonderful, Mollar de Elche	Spain	Temperature22 °C, Duration 6 days, Racking 4 °C, 1 day, Stabilization 10 days, *Saccharomyces bayanus*	TA, TSS, pH, VA, alcohol, organic acid, sugar, anthocyanin, TPC, DPPH, ABTS+, color	Production of wine from different cultivars of secondary quality pomegranate fruits proved to be a good avenue to utilize secondary quality fruits through value addition.	[29]
Wonderful, Mollar de Elche	Spain	Temperature 22 °C, Duration 9 days, Racking 4 °C, 1 day, Stabilization 10 days, *Saccharomyces bayanus*	TA, TSS, pH, VA, alcohol	The volatile compound in pomegranate juice and wine differed. Limonene was the most abundant volatile compound in pomegranate juice whereas ethyl octanoate predominated the pomegranate wine.	[50]

Table 4. *Cont.*

Cultivar	Location	Fermentation Conditions	Measured Parameters	Research Findings	Reference
Wonderful, Mollar de Elche	Spain	Temperature 22 °C, Duration 35 days, *Viniferm revelacion*, *Viniferm SV*, *Viniferm PDM* (10^6 CFU/mL)	pH, TA, density, pH, color, sugar, organic acids, alcohol, glycerol, TAC	Pomegranate wines produced using three different (*Viniferm revelacion*, *Viniferm SV*, *Viniferm PDM*) commercial *Saccharomyces cerevisiae* yeast strains showed different patterns in sugar consumption, color evolution, organic acids, ethanol/glycerol concentration during fermentation.	[59]
Hicaz	Turkey	Temperature < 24 °C, Duration 12 days, Active dry yeast, Aging 18 months	pH, reducing sugar, density, alcohol, volatile acidity, TAC, polymeric color, total phenol, antioxidant, individual phenolics	The different maceration methods influenced the quality of wine produced. While wines produced using the classical maceration methods had better alcohol content, phenolic compound and antioxidant activity, the wines produced from seed-supplemented maceration had better aroma compound.	[19]

4. Pre-Fermentation Factors Affecting Pomegranate Wine Quality

4.1. Effect of Raw Material on Wine Quality

Raw materials contribute significantly to flavor by providing microorganisms with precursors of flavor compounds that are essential for aroma [60]. Wine quality and flavor are influenced by the fruit maturity, fruit quality, fruit cultivar, growing soil, and growing year [61,62]. Fruits vary significantly in color, freshness, bitterness, aroma and organic acid. The selection of fruit for juice fermentation is an important stage in wine production as both the technological ripening (sugar and acids) and phenolic ripening (anthocyanin and tannin) affect the quality of wine. The stage of ripening can contribute desirable attributes to wine, including astringency and color properties. Fruits should be harvested at the right maturity stage for the ease of extracting the fermentables; harvesting fruit when it is too ripe or under-ripe affects the extractability of phenolic and color compounds into the must [61].

Several studies have been conducted on the role of raw materials in pomegranate wine quality. Zhuang et al. [27] examined the effect of producing wine using three different cultivars (sweet Qinqpi, sour Qinqpi and Red Mountain Tai) of pomegranate fruit on the antioxidant, chemical compositions and phenolics profiles of pomegranate wine. The study showed that the sweet Qinqpi had the highest total phenolic compounds, alcohol content and DPPH at concentrations of 1596.67 mg/L, 14.11%, 70.58%, respectively, but the Red Mountain Tai pomegranate had a higher total anthocyanin content at a concentration of 82.26 mg/L compared to the sweet and sour Qinqpi. In addition, the sour Qinqpi had a titratable acidity and lower pH at concentrations of 35.90 and 2.56 g/L, respectively, compared to the sweet Qinqpi and Red Mountain Tai cultivar. The chemical profiling of pomegranate wine produced using two distinct cultivars (Jolly red and Smith) was investigated by [34]. The findings from this study show that wines produced from the cultivar "Smith" had a lower pH and a higher concentration of both citric acid and anthocyanin content at a concentration of 10 g/L and 300 g/L, respectively. In addition, the fermentation rate of wines from both cultivars were significantly different. Cultivar "Smith" fermented at a much slower rate (14 days) compared to the Jolly red, which fermented at a much faster rate. Moreover, wines produced from Jolly Red were richer in esters.

Differences in the physicochemical characterization of pomegranate wines produced using three cultivars (Sanbaitian, Jingpitian and Suanshiliur) have also been demonstrated [63]. For instance, the Sanbaitian cultivar was shown to have the highest concentration of alcohol (12.4%) compared to the cultivars "Jingpitian and Suanshiliur", at 11.1 and 9.67%, respectively, even though the sugar levels, fermenting yeast and fermentation conditions were the same for the three cultivars studied. Mena et al. [29] determined the effect of the cultivar (Wonderful and Mollar de Elche) on the phytochemical composition of pomegranate wine. The result showed variations in the concentration of anthocyanin degradation during the wine production process. The concentration of anthocyanins found in Wonderful and Mollar de Elche juice were 136 and 23 mg/100 mL, respectively, but during pomegranate wine production, they reduced by 46% and 56% for Wonderful and Mollar de Elche, respectively. Also, the concentration of gallic acid and total phenolic content ranged from 38.1 mg/100 mL to 390 mg GAE/100 mL, respectively, in wines made from Wonderful compared to wines from Mollar de Elche, which had a gallic acid content of 15.8 mg/100 mL and total phenolic content of 288 mg GAE/100 mL.

The melatonin production in pomegranate wine produced using two different cultivars (Wonderful and Mollar de Elche) was studied by Mena et al. [57]. Findings from this study showed there were variations in the concentration of melatonin produced by the different cultivars studied. The melatonin production in the varietal wines increased from 0 ng/mL to 7.37 and 4.14 ng/mL for Wonderful and Mollar de Elche, respectively, during the first 4 days of fermentation. A general decline in melatonin was observed until the end of fermentation, with Mollar de Elche wine having a 90% loss and Wonderful having a 25% loss.

4.2. Effects of Juice Extraction Methods on Pomegranate Wine Quality

Fruits are rich in nutrients, and the nutrients found on different parts (peels, seeds, and pulp) of fruits vary according to fruit part. The choice of an optimal juicing method is an important factor to be considered in juice production as it affects the physicochemical, phenolic, aroma, and antioxidant properties of juice [64], which will in turn affect the final wine quality. Consumers' desire to maintain a diet that promotes improved health has boosted the demand for juices that retain their natural nutritional value.

All parts of pomegranate fruit are rich in different polyphenolic and antioxidant compounds, and to fully extract these bioactive compounds into the juice, the choice of juice extraction technique should be considered. Pomegranate juice can be extracted using different techniques, including using juice extractors (extracting juice from the arils alone), blenders (crushing the seeds and arils), hand pressers (compressing half fruit that includes the arils together with pith and membrane) and squeezers (squeezing the whole fruit) [25,26,52,65–68]. Depending on the type of extraction method used, these bioactive compounds are found at a much higher concentration than others. The bioactive compounds of juice extracted from the arils only have been reported to have a lower concentration of bioactive compounds compared to those extracted from both the arils and the peels [25,26].

In pomegranate wine production, the method of juice extraction has an impact on the concentration of the bioactive compounds present in the wine. Wasila et al. [52] investigated the effect of pomegranate peel on the phenolic composition and antioxidant activity of pomegranate wine. In their study, pomegranate juice was extracted from arils only and a mixture of arils, epicarp and mesocarp. The concentration of the total phenolic, flavonoid and anthocyanin contents were higher (2.546 mg/g, 0.944 mg/g and

0.332 mg/10 g, respectively) in wines produced from a mixture of the arils, mesocarp and epicarp compared to the wines produced from the arils alone. In addition to the phenolic content, the antioxidant activity and the composite sensory score were also higher in wines produced from a mixture of the arils, mesocarp and epicarp.

Xuan et al. [63] also observed a higher phenolic compound in wines produced from arils and peels. In addition to possessing a higher number of phenolic compounds, wines from peels also show a high higher TRC (total reducing capacity) compared to wines produce from arils only.

5. Microorganisms and Other Abiotic Factors Affecting Pomegranate Wine Quality

Fermentation conditions like temperature, pH, SO_2 concentration and type of fermenting yeast have significant impacts on the preservation of the bioactive compounds found in wine as well as the sensory quality attributes such as aroma, taste, and color. Therefore, to obtain a high-quality product, it is imperative to select the right yeast and optimize the fermentation conditions to suit the raw material.

5.1. Effects of Yeasts on Pomegranate WINE quality

The feasibility of the efficient alcoholic fermentation of pomegranate juice is well documented by several studies in which it was intended as single fermentation for obtaining pomegranate wine.

The development of organoleptic properties in pomegranate wine is dependent on the choice of fermenting microorganisms. The *Saccharomyces* yeast species has been reported as the principal yeast species in pomegranate wine production [32,33,59], even though different lactic acid bacteria has also been proven to effectively ferment pomegranate juice to produce probiotics (Table 5).

Table 5. The effect of yeast on the organoleptic properties of pomegranate wine.

Yeast	Cultivar	Country	Other Quality Attributes	Organoleptic/Volatile Compounds	Reference
Spontaneous fermentation; *Saccahromyces cerevisiae* Actiflore F33	Not stated	China	Fermentation performed using a starter culture had a better physicochemical property (ethanol, sugar utilization) compared to the fermentations performed spontaneously. Wines from spontaneous fermentation had better volatile compounds	Pomegranate wine produced by spontaneous fermentation had higher octanoic acid, decanoic acid, isobutanol and isoamylol compared to wines produced from commercial yeasts	[51]
Saccharomyces bayanus (SB); *Saccharomyces cerevisiae* (SC); *Saccharomyces cerevisiae var. diastaticus* (SCD)	Wonderful	France	Residual sugar after fermentation using the yeast SB, SC and SCD were 4.4 g/L, 5.1 g/L and 10.5 g/L respectively; ethanol level was at a concentration of 7.0, 6.5 and 6.0 respectively	There were significant differences in wines produced using different yeasts with wines fermented with SB having a higher concentration than SC and SCD; also, the concentration of Ethyl octanoate varied having a concentration of 6.15 mg/L in SB, 3.90 mg/L in SC and 13.45 mg/L in SCD	[32]

Table 5. *Cont.*

Yeast	Cultivar	Country	Other Quality Attributes	Organoleptic/Volatile Compounds	Reference
Saccharomyces cerevisiae var. *ellipsoideus*; *Saccharomyces bayanus*; *Saccharomyces beticus*; *Saccharomyces fermentati*; *Saccharomyces uvarum*; *Saccharomyces cerevisiae*-2226; *EC-1118*; *IIHR*	Bhagwa	India	Not stated	Pomegranate wine produced *from Saccharomyces cerevisiae var. ellipsoideus* had the highest score for sensory quality.	[69]
Lactobacillus plantarum; *Lactobacillus delbruekii*; *Lactobacillus paracasei*; *Lactobacillus acidophilus*	Not stated	Iran	*Lactobacillus plantarum* reduced fructose and glucose from 6.3 g/L and 7.51 to 5.3 g/L and 5.5 g/L which was faster than those from other *Lactobacillus* species which shows	Not stated	[17]
Lactobacillus plantarum; *Lactobacillus acidophilus*	Not stated	Iran	*Lactobacillus plantarum* showed a better consumption of glucose and fructose having a residual of 5.49 g/L and 5.27 g/L, respectively compared to *Lactobacillus acidophilus* which showed a lower sugar consumption	Not stated	[28]
Lactobacillus plantarum C2; *Lactobacillus POM 1*; *Lactobacillus plantarum LP09*	Common Molfetta	Italy	Juice fermented with *Lactobacillus plantarum* C2 had a higher antioxidant and polyphenolic compounds	Not stated	[56]
Saccharomyces cerevisiae ex-bayanus EC 1118; *Saccharomyces Clos*	Jolly red, Smith	Italy	*Saccharomyces cerevisiae ex-bayanus EC* 118 showed a complete utilization of sugar during fermentation leaving a residual sugar of 0.29 g/L which was lower than those found in wines fermented with *Saccharomyces clos* (2.41 g/L)	Acetate esters, ethyl esters were higher in wines fermented with *Saccharomyces cerevisiae ex-bayanus EC 1118* irrespective of the cultivar used	[33]

Table 5. *Cont.*

Yeast	Cultivar	Country	Other Quality Attributes	Organoleptic/Volatile Compounds	Reference
Viniferm revelacion; Viniferm SV; *Viniferm PDM*	Wonderful	Spain	Residual sugar was 4.05 g/L, 5.19 g/L and 5.95 g/L for wines produced from *Viniferm SV*, *Viniferm PDM* and *Viniferm revelacion* respectively; alcohol content was highest (11.15%) in wine produced from *Viniferm SV* compared to wines from *Viniferm revelacion* and *Viniferm PDM* having an alcohol level of 10.62% and 10.97% respectively	The yeast *Viniferm revelacion* produced the highest glycerol content during fermentation, having a concentration of 1.51 g/L	[59]
Lactobacillus plantarum; Lactobacillus acidophilus; Bifidobacterium bifidum; Bifidobacterium longum	Not stated	Spain	The concentration of epicatechin and catechin present in the fermented juice was highest in those fermented with *Bifidobacterium longum* having a concentration of 3.59 mg/100 mL and 90.28 mg/100 mL for epicatechin and catechin respectively	Not stated	[31]

Cardinal et al. [33] monitored the fermentation process and chemical profiling of pomegranate wines obtained by using different commercial yeasts. A faster fermentation rate was observed when fermenting with *Saccharomyces cerevisiae ex-bayanus EC1118* compared to fermentation using *Saccharomyces cerevisiae Clos*. Despite the same amount of potassium metabisulfite being added in all the fermentation tanks, the wines obtained by the yeast *Clos* had a lower total SO_2 content. Similarly, Kokkinomagoulos et al. [32] evaluated the effect of three different Saccharomyces yeast strains (*Saccharomyces bayanus*, *Saccharomyces cerevisiae* and *Saccharomyces cerevisiae var. diastaticus*) on the physicochemical characteristics, antioxidant and aroma compounds on pomegranate alcoholic beverage production. Higher amounts of residual sugars were detected in wines produced by *Saccharomyces cerevisiae var. diastaticus*. Ethanol content was affected significantly by yeasts, with *Saccharomyces bayanus* producing more ethanol at a concentration of 7.0% (*v*/*v*). The concentration of phenolic compounds, DPPH, esters and total alcohols were higher in wines produced from *Saccharomyces cerevisiae* var. *diastaticus*.

Berenguer et al. [59] investigated the physicochemical characterization of pomegranate wine fermented with three different *Saccharomyces cerevisiae* (*Viniferm revelacion*, *Viniferm SV*, *and Viniferm PDM*) yeast strains. The wine fermented with Viniferm SV had a greater ethanol level (11.15%) and the lowest residual sugar (g/L) compared to the other yeasts. In addition to ethanol, the color evolution during fermentation was also evaluated using the CIELab system of chromatic coordinates. Statistical differences were found for CIELab parameters. The wine fermented with *Viniferm SV* had a higher lightness CIEL, hue angle and chroma, while *Viniferm PDM* showed the highest CIEa value, which determines the intensity of the red color. Total anthocyanin was also the highest (141.76 mg/L) in wines produced from the yeast *Viniferm PDM.*

5.2. pH

Optimum pH is necessary for yeast growth. Yeast growing at a very acidic or alkaline pH can undergo chemical stress, which will, in turn, affect the wine quality [70]. The pH of pomegranate juice ranges between 2.56 and 4.30 depending on the cultivar and the juice extraction method [25,26,29]. Pomegranate juice with a low pH usually leads to a corresponding lower alcoholic content during fermentation as the low pH stresses the yeast cells, which leads to a longer time for the yeast to adapt to the medium [29,33]. Samson et al. [71] evaluated the effect of pH on pomegranate wine production using different pH ranges (3.0, 3.5, 4.0, 4.5, 5.0). The alcohol concentration increased significantly with an increase in pH up to 4.0 (6.6–9.8%) and less alcohol (6.4%) after that point. Based on a literature search, there are few studies that have evaluated the effect of pH on pomegranate wine quality. Therefore, to ensure the production of high-quality pomegranate wine, more research needs to be conducted to optimize the appropriate pH suitable for yeast growth during pomegranate wine fermentation.

5.3. Temperature

Temperature control is important in wine fermentation. High temperatures encourage rapid oxidation, microbial spoilage, and the rapid loss of volatile compounds. On the other hand, fermentation at a low temperature retains more volatile compounds but also slows down yeast growth, which might lead to stuck fermentation [72,73]. Therefore, the choice of the right fermentation temperature (greater than 15 °C but less than 25 °C) increases yeast growth, produces better volatile compounds, and enhances the production of glycerol, which counters the bitterness of tannin, thereby generating a smoother mouthfeel.

Even though the temperature to produce grape wine is well established, few studies have investigated the effect of fermentation temperature on pomegranate wine quality. Kokkinomagoulos et al. [32] considered different temperatures (15 °C and 25 °C) to assess their effect on the physicochemical characteristics, antioxidant activities and aroma compounds of pomegranate wine. Wine fermented at 15 °C had more residual sugar (10.5 g/L), a high pH (3.10), high volatile acidity (0.33 g/L acetic acid), low ethanol content (5.6%) and low TA (16.2 g/L citric acid).

The temperature used in pomegranate wine fermentation is still based on that developed for grape wine production. Therefore, it is necessary to establish an optimum temperature that will be suitable for pomegranate wine production.

5.4. TSS

Sugar is one of the most important nutrient requirements for fermenting yeast. Yeast utilizes the sugar and other nutrients in the juice and converts them to ethanol and other byproducts. Even though the yeasts require sugar as the main carbon source for growth and multiplication, very few yeasts can tolerate a sugar concentration > 40 °Brix. Depending on the style of wine and the intended alcohol level to be reached, sucrose and other sugar materials like honey and juice concentrate may be added to the pomegranate juice to increase the TSS level, which in turn increases the sweetness/alcohol level of the wine.

Singh et al. [74] determined the effect of fermenting pomegranate juice using different levels of sugar concentration (20 °Brix–40 °Brix). Juice fermented with sugar > 30 °Brix had the lowest alcohol content and aroma compounds. It also had the least level of acceptability and color appearance after 30 days of fermentation. The effect of different concentrations of sugar syrup (0, 15, 20, 25 and 30 °Brix) on the physicochemical quality of pomegranate was studied by Ulla et al. [75]. Findings from this study showed that even though pomegranate juice fermenting at an initial sugar concentration of 30 °Brix begins poorly, after 24 h, it performed better in terms of physicochemical quality attributes. The alcohol content and residual sugar present in wines fermented at sugar concentrations of 30 °Brix was 9.35% and 11.50 °Brix, respectively. Based on the residual sugar observed in this study, fermenting at a higher initial sugar concentration is suitable for producing sweet pomegranate wine, which usually contains a higher amount of residual sugar. In addition, Kokkinomagoulos et al. [76]

studied the impact of adding different sugar types (sucrose, concentrated pomegranate juice, concentrated grape juice and honey) on pomegranate wine fermentation. Findings showed that the sugar type added made a significant difference to the final wine quality, as total phenolics and esters were higher with wines fermented with added concentrated pomegranate juice. Furthermore, higher glycerol and ethanol concentrations were found in wines fermented with added honey. Antioxidant, phenol, flavonoid and anthocyanin levels were shown to be higher in pomegranate wines made from fresh juice (13 °Brix) without sugar addition but juices with sugar added up to 25 °Brix had a higher alcohol level than the fresh juice.

A similar study by Attri. [77] showed that when producing cashew wine at different sugar concentrations (20, 22 and 24 °Brix), wines produced at an initial sugar concentration of 24 °Brix had a lower fermentation rate (57.94%), indicating the adverse effect on the fermentation efficiency of the yeast. The initial sugar concentration significantly affected the concentration of aldehydes, total esters, and phenols. A higher initial sugar concentration led to increased esters and phenols, with a significant decrease in aldehydes.

5.5. TA

The overall acid concentration in a food sample is measured by titratable acidity. It influences the flavor (by adding tartness), color (by influencing anthocyanin and other pH influencing pigments) and microbial stability of food samples [78]. An increase in TA causes a decrease in pH and vice versa. When the pH of the juice is too low, it leads to an acidic medium that is usually uncomfortable for the growth of yeasts. On the other hand, an increase in pH tilting towards neutral (7.0) favors the growth of many microorganisms, which can lead to potential spoilage of the juice.

The TA of a mature pomegranate fruit ranges from 1.55 to 1.78 [25,26,37] depending on the cultivar and the juice extraction method. The taste of a juice is not only determined by the total soluble solid (TSS) but also the concentration of the TA present in the juice sample. Finding the ratio between the TSS and TA, also known as the BrimA index, plays a role in juice flavor and acceptability. The BrimA index is calculated as follows: BrimA index = $\text{TSS} - k \times \text{TA}$, where k is the tongues sensitivity index, usually ranging from 2–10. The BrimA index increases with fruit maturity, and the higher the BrimA index, the more acceptable the taste [37].

Even though BrimA plays a role in the flavor and acceptability of pomegranate juice, to the best of our knowledge, no study has monitored/reported the effect of the TA or BrimA index on the acceptability of pomegranate wine. Therefore, more research is needed to understand the relationship between BrimA and consumer acceptance of pomegranate wine.

6. Techniques Used in Analyzing Pomegranate Juice and Wine Products

6.1. Subjective Sensory Assessment of Pomegranate Wine Quality

The two main methods used in sensory analysis are analytical tests and hedonic tests. Analytical tests seek to find out the perceived difference between samples and the magnitude of the differences, while hedonic tests assess consumer acceptability and the degree/extent of likeness by consumers. Various studies, as outlined in Table 6, have been conducted to evaluate consumers' perception of pomegranate wine. A sensory lexicon containing 34 referenced and defined attributes for classifying pomegranate juice and juice products was developed and reported by Koppel and Chambers [79]. These attributes include apple, beet, berry, brown spice, brown sweet, carrot, candy-like, cranberry, cherry, fermented, floral, fruity, fruity-dark, grape, green-viney, honey, metallic, molasses, musty/earthy, pungent, sweet overall, vinegar, wine-like, woody, sweet, sour, bitter, astringent, toothetch, metallic, chalky, tongue tingle, tongue numbing, and throat burn.

Table 6. Consumer perceptions of pomegranate wine.

Cultivar	Physicochemical Properties of Pomegranate Wine	Quality Attributes Evaluated	Panelists (Trained and Untrained)	Consumer Perception	References
Hicaz	TSS 21 °Brix, ethanol 12.8%	Color, clarity, odor, taste	Seven panelists (2 females, 5 males)	The sensory properties of the wines produced by enzymatic maceration was higher than those produced from classical and seed maceration	[19]
Gabsi	TSS 15.1 g/L, pH 3.50, TA 9.35 g/L, ethanol 61.23 g/L	Wine character, pungent sensation, red fruit, wood character, general impression	Six trained panelists (2 females and 4 males)	Pomegranate vinegar showed high acceptability by consumers, having a red fruity character	[20]
Mollar de Elche	N/A	Color, sweet, sour, bitter, astringent, fresh pomegranate, fresh rind, earthy, mushroom	Eight Trained panelists (4 females, 4 males)	Consumers showed preference for fresh juices than the processed ones.	[24]
Apaseo	pH 3.07–3.10, TSS 11.3–12.3%, ethanol 11.4–12.4%	Appearance, color, aroma, sweetness, flavor, and general acceptability	Twenty Trained panelists	Consumers showed acceptance for the fermented pomegranate beverage irrespective of treatment (HHP and pasteurization)	[80]
Common Molfetta	N/A	Anise, astringent, berry, fermented, floral, fruity, grape, pungent, sour, sweet, vinegar, wine-like, molasses	Ten trained panelists (5 females, 5 males)	The sensory profile of fermented pomegranate juice using a starter culture were preferred compared to the raw juice	[81]
Wonderful; Mollar de Elche	Wonderful (pH, TA, VA, Alcohol; 3.12, 20.22 g CA/L, 0.33 g/L, 8.30%); Mollar de Elche (pH, TA, VA, Alcohol; 3.35, 4.56 g CA/L, 0.26 g/L, 9.05%)	Color, anise, astringent, beet, berry, bitter, blackberry, cherry, cranberry, fermented, floral, fruity, fruity-dark, grape, grape-viney, pomegranate, pungent, sour, sweet, throatech, toothetch, vinegar, wine-like	Ten trained panelists (6 females, 4 males)	The trained panel characterized the fermented pomegranate wine based on appearance and color. Wines made from Mollar de Elche had the highest intensity in terms of odor and flavor, on the other hand, wines made from Wonderful had more intense red color	[50]

Table 6. *Cont.*

Cultivar	Physicochemical Properties of Pomegranate Wine	Quality Attributes Evaluated	Panelists (Trained and Untrained)	Consumer Perception	References
N/A	Acetic acid content 5.50%, alcohol content 3%,	Color, odor, sweet, sour	Thirty untrained panelists	Using the 9-point hedonic scale to assess the levels of consumer preference, the sensory score revealed a great acceptance of the product by the consumer	[82]

Total soluble solids (TSS), titratable acidity (TA), volatile acidity (VA), information not available (N/A), citric acid (CA), high-hydrostatic pressure (HHP).

Andreu-Sevilla et al. [50] used this lexicon to assess the sensory descriptive analysis of wines produced using the pomegranate cultivars Wonderful (sour) and Mollar de Elche (sweet), as well as a blend of both cultivars (Coupage), using trained panels. Twenty-three (color, anise, astringent, beet, berry, bitter, blackberry, cherry, cranberry, fermented, floral, fruity, fruity-dark, grape, grape-viney, pomegranate, pungent, sour, sweet, throatech, toothetch, vinegar, wine-like) attributes were used in the sensory evaluation of pomegranate wine. The wine produced from the cultivar "Mollar de Elche" had the highest intensities of several odor notes, including cherry, floral and fruity. The highest odor intensities of wines produced from the Wonderful cultivar were characterized as green-viney and wine-like. The flavor intensities of anise, blackberry, fermented and fruity were more intense in wine produced from Mollar de Elche, while a green-viney and cranberry flavor was most abundant in wines from Wonderful.

Kharchouf et al. [20] investigated the sensory profile of pomegranate vinegar using a trained panel. The results showed that the sensory panel accepted pomegranate vinegar as a potential product mainly due to its red fruity character. The influence of juice pretreatment (high hydrostatic pressures at 500 MPa/10 min, 550 MPa/10 min, 600 MPa/5 min and pasteurization) on the sensory profile of fermented pomegranate juice was studied by Rios-Corripio et al. [80]. Consumers showed an acceptability of the fermented beverage irrespective of the treatment.

6.2. Objective Measurements of Pomegranate Wine Quality

6.2.1. Wet Chemistry

Wet chemistry is an old/traditional method used in the analysis of chemical compounds. It can also be called bench chemistry as the analyses are performed in the liquid phase and usually on a lab bench. Wet chemistry is a qualitative assay used to measure or determine the presence of a specific chemical rather than the exact amount. The processes involved in wet chemistry include extraction, distillation, precipitation, and qualitative analysis by color [83].

In addition to the more precise and sophisticated techniques used in the analysis of chemical properties in food and beverage industries like spectroscopy and omics technology, wet chemistry is still very much in use. Some fundamental experimental methods used in wet chemistry include the analysis of pH, titratable acidity, conductivity, density, viscosity, and specific gravity; moisture analysis; fat characterization, protein analysis; fat analysis; ash analysis; carbohydrate analysis; and vitamin analysis [84]. In pomegranate wine production, wet chemistry is used in determining changes in pH, TSS, TA, color, volatile acid, density and free and total SO_2 during the wine production process (Table 7).

Table 7. Different wet chemistry techniques used in measuring pomegranate wine quality.

Parameters	Instrument used	Result	References
pH, TSS, TA	MP220 portable pH-meter, A. Kruss Optronic refractometer	There were variations in the pH, TSS and TA during pomegranate wine fermentation and after wine aging. While the TSS and pH decreased during fermentation, the TA value significantly increased	[30]
pH, TA, color, Shade	Not stated	There were remarkable differences in the pH, TA, color intensity of wines produced from three different pomegranate cultivars. TA value was higher in wines produced from sweet and red pomegranate cultivar but was lower in sour pomegranate fruit	[27]
pH, TA, TSS, VA	Not stated	The TA and pH increased with a significant decrease in the TSS	[57]
pH, TA, TSS, VA, density	Refractometer, density meter, pH meter	The winemaking process led to an increased TA and acetic acid with a decrease in pH and TSS	[20]
pH, free and total SO_2, density	pH meter, iodometric titration, hydrometer	The pH and SO_2 values were significantly different in the wines obtained from different fruit cultivars and yeasts	[33]
pH, TA, VA	pH meter	pH value of the wine was affected by fermenting at 25 °C, whereas fermentation done at 15 °C had no significant effect on the pH value of the pomegranate wine	[32]
pH, TA, density, color	pH meter, pycnometer, colorimeter	TA, hue angle and lightness of the wines produced using different yeasts increased significantly whereas the redness and chroma of the wine varied depending on the yeast used in fermentation	[59]
pH, TA, TSS, VA, color	Not stated	TA and pH increased across all varietal wines. In the color measurement, there was an increase in the lightness and redness of the fermented pomegranate wine with a corresponding decrease in hue angle and chroma across all varietal wine produced	[29]

Total soluble solids (TSS), titratable acidity (TA), volatile acidity (VA), sulfur dioxide (SO_2).

Lan et al. [30] measured changes in the pH, TA and TSS during pomegranate wine fermentation and aging. The results showed the evolution of these quality parameters during the winemaking process. The pH value decreased to the lowest value (3.27 ± 0.01) initially and then slightly increased up to day 10. On the contrary, the TA value increased until day 6 of fermentation and slightly decreased to the end. The TSS, on the other hand, decreased from 20 to 6.90 °Brix. Also, variation in the pH, VA, TA, TSS and density of wines produced using three different maceration methods (classical, seed-supplemented, and enzyme/seed supplemented maceration) was measured by Akalin et al. [19]. Using the titrimetric method, total acidity was found to decrease during the winemaking process (28.7 g/L–22.7 g/L), with the lowest value recorded for wines produced from seed-supplemented maceration compared to the other macerations methods investigated.

Similarly, Zhuang et al. [27] monitored changes in the pH, TA, color intensity and shade produced from three different cultivars (sweet, sour, and red) of pomegranate fruits using a compendium of international methods of wine and must analysis (O.I.V.) [85]. Findings from this study showed that wet chemistry was suitable for determining changes in the chemical compositions during wine fermentation. The pH values reduced significantly during the winemaking process irrespective of the cultivar used. The highest reduction in pH was observed in wines produced from the sour cultivar. All the varietal wines produced had no SO_2. Similarly, during the winemaking process, the color intensity of varietal wines was significantly different. While the color intensity of the red pomegranate cultivar was the lowest (0.653) compared to the sweet and sour cultivar, the sour pomegranate recorded the highest (1.372) color intensity in the investigated cultivars. Contrary to the method used by Zhuang et al. [27], Berenguer et al. [59] used the IFU1 and IFU3 methods of the International Federation of Fruit Juice Producers (Paris, France) to determine the titratable acidity and density during pomegranate wine production using three different yeasts. Findings from this study show a fluctuation in the pH (3.40–3.58) and density values (1.24.05–9.52 mg/L). A significant increase (2.81–6.03 g citric acid/L) was also observed in the TA value during the wine fermentation process until day 9 of the fermentation, after which it remained constant until the end of the fermentation.

6.2.2. Metabolomics

The metabolites found in plant foods play a role in the sensory perception of food and its quality attributes. A deep understanding of these metabolites is necessary, especially in food processing industries, to improve food quality, food safety, food regulation, food processing and nutrition related to these quality attributes [86–89].

Metabolomics targets the volatile and non-volatile compounds present in wine and quantifies these metabolites using targeted and non-targeted approaches [90,91].

In pomegranate wine production, metabolomics has been used to characterize and monitor changes during fermentation (Table 8). The analytical techniques involved in metabolomics include the use of spectroscopy, such as mass spectroscopy, which is often coupled with chromatography. Lan et al. [30] employed HS-SPME-GC-MS to analyze changes in volatile compounds found during pomegranate wine production, and the findings from these studies showed that esters, alcohols, acids, aromatic compounds, hydrocarbons and heterocyclic, aldehydes and ketones, and alcohols were the six kinds of flavors identified in the winemaking process. These volatile compounds changed during the process of winemaking and -aging, with heterocyclic and aromatic compounds dominating the first days of fermentation while esters and alcohols dominated the last phase of fermentation. HPLC was used to analyze the individual phenolic compounds found in pomegranate wine treated with three different macerations (classical maceration, seed-supplemented maceration, seed + enzyme supplemented maceration). Gallic acid content in wines produced from seed-supplemented maceration and seed + enzyme supplemented maceration was higher compared to classical maceration, and this was as a result of the hydrolysable tannins of the seeds [19].

Table 8. Different metabolomics technologies that have been used in pomegranate wine quality analysis.

Methodology	Application	Research Findings	References
HS-SPME-GC-MS	Determine volatile compounds found in spontaneous fermentation and starter culture fermentation	More volatile compounds were found in the starter culture-inoculated wines compared to the spontaneously fermented wine	[51]
HS-SPME-GC-MS	Analyze volatile compounds in wine samples	Six volatile compounds were present in fermented pomegranate wine, and the concentration of the volatile compounds varied across fermentation days	[30]

Table 8. *Cont.*

Methodology	Application	Research Findings	References
HPLC	Determine individual phenolic compounds in pomegranate wine	Catechin and gallic acid were identified as the dominant phenolic compounds in pomegranate wine	[19]
LC-ESI-MS	Determine melatonin production in pomegranate wine	Melatonin was detected in fermented pomegranate wine but was absent in pomegranate juice	[57]
UPLC	To monitor the evolution of polyphenolic and volatile compounds in pomegranate vinegar	There was an increase in polyphenolic compounds during alcoholic fermentation, and they decreased slightly during acetic fermentation. Esters, alcohols, and terpenes were the main volatile compounds in pomegranate vinegar, but after acetification, the concentration of ethyl esters decreased with an increase in acids	[20]
HPLC GC-MS	To determine organic acid content and volatile compounds	Citric acid was found to be the most abundant organic acid present in pomegranate wine, with tartaric acid, ascorbic acid, lactic acid, acetic acid, and succinic acid present at much lower concentrations. Results obtained from the compounds indicated the presence of 46 different volatiles, with esters and alcohols being the most dominant	[33]
HPLC LC-MS	Determination of sugar, organic acid, anthocyanins and ellagic acid	Changes were observed in the kinetics of sugar consumption, and the extent of the observed changes was dependent on the substrate and duration of fermentation. Five organic acids were produced during fermentation, with citric acid being the most dominant. Also, a significant decrease was found in anthocyanin and ellagic acid content during pomegranate wine fermentation	[28]
HPLC	Sugar and organic acid were identified in fermentation using probiotic lactic acid bacteria	Citric acid was the dominant organic acid in pomegranate juice, and it was found to decrease during fermentation. Glucose was completely consumed by the lactic acid bacteria compared to fructose	[17]
HPLC-DAD	Determination of the biotransformation of phenolic compounds in fermented pomegranate juices	An increase in ellagic acid was observed after fermentation using different lactic acid bacteria. On the other hand, there was a significant decrease in the concentrations of α- and β-punicalagin	[31]
HPLC HS-SPME-GC-MS	Determination of ethanol, glycerol and aroma compound in wine produced using three different yeasts	Ethanol concentration varied significantly depending on the fermenting yeast used, while the same pattern of glycerol production was observed irrespective of the yeast used. The concentration of volatile compounds identified also varied according to the yeast used in the fermentation process	[32]
LC-MS GC-MS	Identification and chemical characterization of the phenolic compounds in commercial pomegranate wine	The use of LC-MS detected a total of eighty-one different phenolic compounds and one hundred and eight compounds were detected by GC-MS	[41]

Table 8. *Cont.*

Methodology	Application	Research Findings	References
HPLC	Changes in polyphenols, sugar and organic acids found in pomegranate wine produced from two different cultivars	Glucose was completely utilized, and residues of fructose were found after the wine irrespective of cultivar. Also, citric was found to be the dominant acid in the fermented pomegranate wines. Losses in the anthocyanin content were significantly different in the different cultivars used	[29]
GC-MS	Describe changes in volatile composition during pomegranate wine production	Terpenes were the dominant volatile compound in pomegranate juice, while esters and alcohols were dominant in the fermented juice	[50]
NMR	Chemical characterization of pomegranate wine produced using different yeasts and cultivars	NMR analysis showed statistical differences between wines produced using different cultivars and yeast combinations, also a positive correlation was found between the metabolites produced and organoleptic parameters.	[92]

LC-ESI-MS was used in the detection of melatonin in pomegranate wine fermented using two different cultivars (Wonderful and Mollar de Elche). Findings from these studies showed that melatonin was absent in pomegranate juice but was detected in fermented pomegranate juice, suggesting the possibility that the fermenting yeast synthesized the melatonin during alcoholic fermentation. Also, the melatonin concentration varied among the cultivars used, with the highest concentration (5.50 ng/mL) found in wines produced from the Wonderful cultivar compared to wines produced using the Mollar de Elche (0.54 ng/mL). Also, Cardinal et al. [33] employed the use of HPLC and GC-MS to profile the volatile compounds and organic acids present in pomegranate wine produced using different yeast (*Saccharomyces bayanus* strain *EC1118*, *Saccharomyces cerevisiae* strain *Clos*) and cultivar combinations (Smith and Jolly red). Their study established significant differences in the organic acid profile of the produced wine, with the cultivar having more effect on organic acid content than yeast; significant differences were also observed in the volatile compounds found in the produced pomegranate wine, and the differences were due to both cultivar and yeast variables. *Lactobacillus plantarum* and *Lactobacillus acidophilus* were used as starter cultures for pomegranate wine production, and the changes in sugar kinetics, organic acids, anthocyanin and ellagic acids were monitored using HPLC and LC-MS. Both methods (HPLC and LC-MS) were able to detect changes in the sugar, organic acid, and phenolic content during pomegranate wine fermentation. Significant differences were observed in the sugar consumption pattern, with *Lactobacillus plantarum* consuming more sugar than *Lactobacillus acidophilus*. Also, *Lactobacillus acidophilus* produced lower lactic acid levels (4.9 g/L) when compared to that produced by *Lactobacillus plantarum* (6.1 g/L). Kokkinomagoulos et al. [32] employed HPLC and HS-SPME-GC-MS to evaluate the effect of ethanol, glycerol and aroma produced during pomegranate wine production using three different yeasts. The yeasts used in fermentation had a significant effect on the levels of glycerol and ethanol produced, ranging from 2.65 to 6.05 g/L and 5.6 to 7.0%, respectively.

Changes in the volatile compounds produced during the fermentation of pomegranate wine using starter cultures and spontaneous fermentation were quantified using GC-MS by Wang et al. [51]. A total of 71 volatile organic compounds (14 alcohols, 29 esters, 7 acids, 14 aromatics, 3 sulfur compounds and 4 ketones) were identified, with 38 found in the spontaneous fermentation and 42 found in the starter culture-inoculated fermentation at the beginning of fermentation. The volatile compounds in the starter culture-inoculated fermentation increased to 58 during wine fermentation [51].

7. Conclusions and Future Prospects

Among the strategies to valorize fruits and vegetables, fermentation is one of the most valuable tools, helping to provide various healthy foods and beverages. Pomegranate fruit is a raw material for fermentation, owing to its richness of fermentable sugars and bioactive compounds. Effective fermentation processes could present the opportunity to satisfy consumers' demand for healthy and sustainable foods while reducing postharvest losses and waste. When considering the fermentation process for pomegranate wine production, both the abiotic and biotic factors affecting wine quality should be exploited and optimized. Although pomegranate wine is available on the market and the optimization of fermentation process has been performed using single-factor optimization, there is no scientific evidence of the use of central composite design to show how these fermentation conditions interact and influence the outcome of pomegranate wine. Various measurement and analytical techniques have been employed for both qualitative and quantitative study of pomegranate wine quality. The literature evidence shows that metabolomic approaches (high-performance liquid chromatography (HPLC), liquid chromatography mass spectrometry (LC-MS), gas chromatography mass spectrometry (GC-MS), nuclear magnetic resonance (NMR), ultra performance liquid chromatography (UPLC), liquid chromatography electrospray ionization-tandem mass spectrometry (LC-ESI-MS), and headspace solid-phase microextraction coupled with gas chromatography-mass spectrometry (HS-SPME-GC-MS)) offer high sensitivity for the identification and measurement of a broad range of secondary metabolites and volatiles during pomegranate wine fermentation. Although routinely applied on other types of wine with considerable success, studies on the pomegranate wine fermentation microbiome are in their infancy, and these include high-throughput sequencing for diversity analysis, metabolomics for un-targeted metabolite profiling, metaproteomics for studying proteins that are expressed by an organism within an ecosystem, and metatranscriptomics for the analysis of metagenomic mRNA. E-tongues and E-noses are used in the food industry to determine the quality of food and beverages by detecting and analyzing changes in taste and aroma, but this technique has not been fully explored in the pomegranate wine industry. As opposed to the human senses, which experience tiredness, this technology may deliver objective replies irrespective of physiological states or individual preferences.

Future research on pomegranate wine production should focus on using the autochthonous microbiota of pomegranate, such as yeasts and lactic acid bacteria, as potential starter cultures in the production of good pomegranate wine. These indigenous yeasts should be screened based on the following criteria: (i) fermentation performance, where the yeast must ferment quickly, complete fermentation, and produce high ethanol concentrations; (ii) wine quality and character, ensuring the selected yeast produces balanced quantities of flavor compounds without compromising wine quality; and (iii) commercial production viability, where the yeast must be suitable for large-scale cultivation.

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