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CHARACTERISTIC OF PHENOLIC COMPOUNDS OF WINE AND THE INFLUENCE OF RAW MATERIAL AND PRODUCTION PROCESS ON THEIR CONTENT®

Charakterystyka związków fenolowych występujących w winie oraz wpływ zastosowanego surowca i procesu produkcji na ich zawartość®

The tradition of wine production and consumption has been known since ancient times. Consumption of wine is particularly widespread in the Mediterranean countries. Wine is composed mainly of water, ethanol, carbohydrates, organic acids, minerals and phenols that shape the taste, aroma and colour of the final product. Phenolic compounds contained in wine also determine its beneficial effect on health. The aim of this article is to characterize the phenolic compounds of wine, as well as presenting the impact of the raw material and wine production process on phenolic content, as well as its healthy properties.

Key words: wine, phenolic compounds, antioxidant properties, production process.

Tradycja produkcji i konsumpcji wina sięga czasów starożytnych. Spożycie wina jest szczególnie rozpowszechnione w krajach basenu Morza Śródziemnego. Wino składa się głównie z wody, etanolu, węglowodanów, kwasów organicznych, składników mineralnych oraz związków fenolowych, które kształtują smak, aromat i barwę produktu finalnego. Obecność związków fenolowych w winie decyduje także o jego korzystnym wpływie na zdrowie. Celem artykułu jest charakterystyka zawartych w winie związków fenolowych, a także przedstawienie wpływu zastosowanego do produkcji wina surowca oraz procesów produkcji wina na zawartość fenoli, jak również ich prozdrowotne właściwości.

Słowa kluczowe: wino, związki fenolowe, właściwości antyoksydacyjne, proces produkcji.

INTRODUCTION

The tradition of wine production and consumption has been known since ancient times. Consumption of moderate amounts of wine is particularly widespread in the countries of the Mediterranean basin, thus making wine one of the basic elements of the traditional Mediterranean diet recommended in the prevention and prophylaxis of cardiovascular diseases [18]. The health-promoting effect of wine is related to the phenolic compounds present in it, which have a wide spectrum of biological activity, potentially beneficial for health [71]. The interest of profile and action of phenolic compounds present in wine started the 1990s, with an attempt to explain the incidence of cardiovascular diseases in the French lower than in other countries. Especially that the diet of the French, like most Europeans, was characterized by an excessive amount of fat [48]. Scientists found a correlation between the consumption of moderate amounts of red wine and the reduction of the risk of cardiovascular diseases [86] and the observed effects were related to the beneficial impact of phenolic compounds present in red wine on lipid parameters and strengthening the body's defense against free radicals [15]. The high content of phenols in wine is desirable not only for their beneficial health effects, but also for technological reasons, as phenols protect the wine against oxidation [6].

The phenolic content of wine depends on many factors, namely the grapevine variety, the location of the vineyard, the cultivation system, climate, soil type, grapevine, harvest time, production and storage process [20]. Wine is produced from grapes, but in recent years there has been growing interest and demand, and consequently the production of fruit wines [92], depending on the region produced from apples, blueberries, cherries, apricots, pears, plums, peaches, strawberries, currants, kiwi, bananas, figs, pineapples, pomegranates, lemons, mandarins or oranges [35]. Taking into account that fruits are a valuable source of not only vitamins and minerals, but also phenolic compounds [29], wine produced from them can be an alternative to traditional wine made from grapes. Fruit wines, as well as grape wines, contain phenolic

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compounds, but, they are characteristic for the fruits from which they were produced [47].

The aim of this article is to characterize the phenolic compounds of wine, as well as presenting the impact of the raw material and wine production process on phenolic content.

ENERGY AND NUTRITIONAL VALUE OF WINE

The composition of wine is varied, determined by many factors, including the climatic and soil conditions specific to the wine-growing area, the type of vines used, the degree of fruit maturity and the method of production. Wine contains on average about 60–90% of water, 9–18% volume of ethyl alcohol, carbohydrates (e.g. glucose, fructose, sucrose), organic acids (e.g. tartaric, malic, amber), higher alcohols (including e.g. propanol, hexanol, glycerol), esters (e.g. ethyl acetate, ethyl formate, ethyl tartrate), aldehydes (e.g. acetaldehyde), vitamins (e.g. B_1, B_2, niacin), minerals (e.g. potassium, sodium, magnesium, calcium) [53], whereby the sweet wine has the highest energy value, which is related to the higher carbohydrate content, while the content of minerals and vitamins, regardless of the type of wine, is similar (Table 1).

Table 1. Energy and nutritional value of red and white wine [42]

Tabela 1. Wartość energetyczna i odżywcza czerwonego i białego wina [42]

Parameters	Red wine	White dry wine	White semi-dry wine	White sweet wine
100 ml				
Energy (kcal)	68	66	81	95
Water (g)	89,9	90,2	86,6	83,5
Carbohydrates (g)	0,2	0,6	3,7	5,9
Potassium (mg)	110	61	70	110
Phosphorus (mg)	13	6	7	13
Magnesium (mg)	11	8	4	11
Calcium (mg)	7	9	10	14
Sodium (mg)	7	4	3	13
Iron (mg)	0,9	0,5	1,8	0,6
Niacin (mg)	0,01	0,01	0,05	0,01
Vitamin B6 (mg)	0,02	0,02	0,02	0,01
Vitamin B2 (mg)	0,01	0,01	0,005	0,01

Classic wine is made from grapes, while fruit wines are made from fruits such as peaches, plums, apricots, bananas, elderberry and blackcurrant, which means that they contain most of the ingredients present in fruit juice. During fermentation, amino acids and other ingredients are released from yeast, which increases the nutritional value of fruit wine. The energy value of fruit wines ranges from 70 to 90 kcal per 100 ml, the carbohydrate content is about 2–3%, and the ethyl alcohol content is usually about 8–11% [78]. When alcohol level of wine is considered, fruit wines can be classified as table wines or fortified wines. Table wines usually contain 11–16% ethanol, but can be also only 7%. Ethanol content in fortified wines ranges from 16% to 23% and the ethanol content is higher if brandy is added [41].

CHARACTERISTICS OF PHENOLIC COMPOUNDS IN GRAPE WINE AND ITS PROPERTIES

There are phenolic compounds in wine, which constitute a large group of secondary metabolites with a very complex structure that shape the organoleptic properties of wine, in particular its colour, taste and aroma [9]. In grapes, these compounds are mainly in the skin and seeds [72], and they protect the plant against fungi and UV radiation [74]. In the literature, several classifications of phenols are distinguished [102, 58], according to one of them [102], phenolic compounds can be divided into four categories: containing one phenolic ring (benzoic and cinnamic acids), containing two phenolic rings (stilbenes), containing three phenolic rings (anthocyanins, flavanols and flavan- 3-ole) and more complex structures (ellagic acids). According to another classification [58], phenolic compounds can be divided into two groups: flavonoids and non-flavonoids. There are mainly flavonoids in wine, namely flavanols, anthocyanins, flavan-3-oils and oligomeric or polymeric condensed tannins called anthocyanidins (delphinidin and pelargonidine).

Flavonoids are low molecular weight compounds composed of a tricyclic structure with various substituents, which gives them a variety of structures. They are found in the skins of both red and white grapes [22]. Flavanols, which mainly protect plants from UV radiation, are found in the skins and pulp of grapes [39], but are also produced in the vinification process (quercetin, kaempferol, myricetin) [58]. Flavanols form oligomers and polymers (condensed tannins) that shape the tartness and bitterness of the wine [58], additionally interact with saliva proteins, enhancing the feelings of tartness and bitterness of wine [8]. The colour of red wines is given by anthocyans which are water-soluble flavonoid pigments, and depending on the pH, they can give different colours such as red, purple and blue [52]. Typically, anthocyans are found mainly in the grape skins, with some grape varieties also containing anthocyans in the grape pulp [76].

The group of non-flavonoids includes three groups of compounds: hydroxycinnamic acids, stilbenes (including resveratrol) and phenolic acids (including gallic, coumaric, caffeic and ferulic acid) [11, 68]. Phenolic acids are found in the skins of red grapes and in the cell vacuoles of the grape flesh, they have no colour but can oxidize giving them a yellow colour. Phenolic acids do not affect the sensory properties of wine, but are of technological importance as they are precursors of some volatile phenolic compounds produced by microorganisms during the wine-making process [87]. Phenolic acids can be classified into two main groups, benzoic acids and cinnamic acids. Among benzoic acids, gallic acid is the most abundant in wine, and cinnamic acids are present in greater amounts in the skin than in the grape pulp [58].

The beneficial properties of red wine, in particular, are determined by the polyphenols present in it, which are a group of natural compounds with a different structure and exhibiting a broad spectrum of biological activity, potentially beneficial to health [71]. Numerous studies have shown that the beneficial effect of phenols on health is related to their antioxidant properties [17], anti-inflammatory [83], anticancer [98], antidiabetic [7], neuroprotective [31] and cardioprotective [12]. Given that oxidative stress plays a significant role in the pathogenesis of various diseases, investigating the antioxidant capacity of phenols has become the subject of special interest to scientists [44]. As it has been shown, these abilities are conditioned by the presence of numerous hydroxyl groups, and the contribution of polyphenolic compounds in the body's defense against reactive oxygen species consists in the removal of free radicals and chelation of free metal atoms, such as copper or iron, which prevents biochemical reactions generating reactive oxygen species, for example lipid peroxidation [89].

Phenolic compounds, especially flavonoids, have a protective effect on the cardiovascular system, thanks to their anticoagulant, antioxidant, antiproliferative, anti-ischemic and vasodilating properties, and also have antitumor, antiviral and antiallergic properties [100]. A special class of phenolic compounds are stilbens, and the main representative of this group is resveratrol, which is formed in the grapevine in response to fungal infections [22]. The greatest amounts of resveratrol are found in the skins of red grapes, which is why red wine also contains the highest amount of it (2,8–4,3 mg/kg resveratrol in red wines vs 0,1–0,5 mg/kg resveratrol in white wines) [66, 69]. In addition, it has been identified as the substance responsible for the health-promoting benefits of regular moderate consumption of red wine [23]. Resveratrol is characterized by antioxidant [88], anti-inflammatory [45], anti-aggregation [28] and anticancer actions [51]. However, not only resveratrol has antioxidant activity, because phenolic compounds form the so-called antioxidant potential, which is a measure of the body's ability to both defend the body against free radicals and prevent diseases resulting from the so-called oxidative stress [20], that is, a disturbed balance between the production of free radicals and their neutralization.

Due to the production technology, the total phenolic compounds content in white wines is ten times lower in comparison with red wines (~4600 mg/L gallic acid equivalent in red wines *vs* ~360 mg/L gallic acid equivalent in white wines) [66]. The main phenolic compounds in white wine are hydroxycinnamic acids and their derivatives, which are responsible for the antioxidant properties of wine, and by conjugation with tartaric acid, they form tartaric acid esters of hydroxycinnamic acid, constituting 80% of all polyphenols of white grape juice [59].

It is worth adding that the production of wine produces waste, namely bagasse, wine sediment and yeast sediment [36], which are a major problem for the wine industry, because using them as compost turned out to have an adverse effect on the soil [56]. The waste produced during the fermentation of white and red wine contains significant amounts of phenolic compounds and is characterized by high antioxidant activity. The wine waste contains mainly proanthocyanidins, namely catechins and epicatechins, with epicatechin dominating in white wine sediments, and epicatechin in red wine sediment [101]. Considering that these compounds are characterized by a broad pro-health effect, including antioxidant, antihypertensive, anti-inflammatory, antiproliferative, anticoagulant and anti-hyperlipidemic effects [99], as well as antidiabetic and anticancer [1], wine waste may be valuable raw material for their re-use, e.g. in dietary supplements intended for humans. Interestingly, one of the few ways to reuse wine sediment is to try to use it as an additive in ice cream production, which significantly improved rheological and antioxidant properties, while antioxidants from wine sediment were quite stable in the ice cream production process [32]. Grape pomace, which is a by-product of wine production, can be a valuable material for use in the pharmaceutical, cosmetic and food industries, because it contains bioactive compounds [36]. Grape seeds are also a valuable raw material, which can be used to produce oil that is a rich source of tocopherol, carotenoids, linolenic acid, but also resveratrol, quercetin, procyanidins and phytosterols with the possibility of application in the pharmaceutical, cosmetic and food industries [26].

CHARACTERISTICS OF PHENOLIC COMPOUNDS IN FRUIT WINE AND ITS PROPERTIES

Of the fruit wines, the most widespread is apple wine produced mainly in Great Britain, France and the United States, pear wine in France [16], raspberry and plum wine in South Korea [13, 43], while wines from other, less known fruits are produced by small, local producers [78]. Fruit wines, just as grape wines, contain phenolic compounds, but characteristic of the raw material from which they were produced. However, the profile of phenolic compounds in fruit wines and their potential health benefits have not been investigated as thoroughly as in grape wines [47]. Fruit wines are a source of various ingredients, including minerals, carotenoids (carotene and lutein) or phenolic compounds (anthocyanins, flavonols, flavan-3-ol, proanthocyanidins, ellagitanins and phenolic acids) [91]. In the study Ljevar et al. [47] the analysis of phenolic compounds in fruit wines showed that blackberry (1936 mg/L gallic acid equivalent), cherry (2074 mg/L gallic acid equivalent) and blackcurrant (2013 mg/L gallic acid equivalent) wines contained the higher total phenols than strawberry (752 mg/L gallic acid equivalent) and apple (449 mg/L gallic acid equivalent) wines, in addition, cherry (244 mg/L) and blackcurrant (250 mg/L gallic acid equivalent) wines had also the higher total anthocyanin content compared to blackberry (90 mg/L gallic acid equivalent) or strawberry (4 mg/L gallic acid equivalent) wines. Different phenolic composition was also noted for each type of fruit wine, especially for anthocyanins. In the study Čakar et al. [16] the highest amounts, especially of procyanidins, were found in cherry (111,7–134,4 μg/ mL epicatechin, 22,3–29,7 μg/ mL catechin) and blueberry (27,8–24,7 μg/mL epicatechin, 1,7–4,5 μg/mL catechin) wine, while the content of these compounds in other wines was much lower (5,9-7,2 μg/mL epicatechin in black chokeberry wine or 1,3-3,7 μg/mL epicatechin in apple wine). On the other hand, blackberry, cherry, raspberry and currant wines analyzed by

Ljevar et al. [47] also had a significantly higher antioxidant capacity than strawberry and apple wines. Also in the study Stępniowska et al. [84] blackcurrant wine was shown to have the highest concentration of phenolic compounds, tannins and anthocyanins, and the highest free radical scavenging capacity than redcurrant, strawberry, raspberry or grape wine. The reason is that black currant contains the most phenolic compounds and vitamin C, which translates into high antioxidant activity, because the higher the content of phenolic compounds, the higher the antioxidant activity [84]. Čakar et al. [16] noted that the highest total phenolics content was for black chokeberry wine (2414 mg/L gallic acid equivalent), and the lowest for apple wine (584 mg/L gallic acid equivalent). In the study Pantelić et al. [61] it was shown that the profile of phenolic compounds found in cherry wine was more diverse compared to grape wines, and the main phenolic acids found in cherry wine were: caffeic acid, chlorogenic acid, protocatechuic acid, and p-coumaric acid and their content it was much higher in cherry wine than in grape wines. In addition, characteristic only for cherry wine were naringenin and apigenin, and seven anthocyanins, namely delphinidin-3-rutinoside, cyanidin-3-sophoroside, cyanidin-3-pentosylrutinoside, pelargonidin-3-glucosylrutinoside, cyanidin-3-rutinoside, peonidin-3-rutinoside, and pelargonidin-3-glucoside, whereas plum wines are mainly characterized by presence peonidin-3-glucoside, cyanidin-3-rutinoside, peonidin-3-rutinoside, chlorogenic and caffeic acids and rutin [55].

Phenolic compounds present in fruit wines, similarly to those found in grape wines, show health-promoting effects, mainly antioxidant [16], although there is scientific evidence of their possible anti-cancer effects. Fruit wines inhibited the growth of human cancer cells *in vitro* in a dose dependent manner, with blackberry, cherry, raspberry and currant wines being the most effective [47]. In contrast, phenolic acids such as caffeic acid, p-coumaric acid and chlorogenic acid present in fruit wines inhibit the oxidation of LDL lipoproteins *in vitro* [54].

THE IMPACT OF VARIETY, CLIMATIC AND SOIL CONDITIONS ON PHENOLIC CONTENT IN WINE

Phenolic compounds are stable during storage of the raw material, however, in the course of processing comes to significant changes in the content of these compounds and their content in the final product [84]. In the case of grape wine, the content of phenolic compounds depends on the grapevine variety, location of the vineyard, cultivation system, climate, soil type, grape cultivation method, harvest time, production and storage process [20].

In the production of grape wine, mainly French grape varieties are used, which are widely used in wineries around the world, leading in a sense to the globalization of the taste of wine produced from specific grape varieties. Some wine producers re-use local grape varieties, analyzing their suitability for the wine industry [50]. In the study Kallithraka et al. [37] the content of phenolic compounds was analyzed in rare native varieties of Greek grapevines that are not used for wine production. It was noted that some of the rare varieties, e.g. *Karvouniaris*, *Thrapsa*, *Nerostafilo*, *Bakouri*, *Vertzami* contained significant amounts of phenols, which means that they are a very good raw material for the production of quality wines.

Grapes are a source of phenolic compounds, but the great variety of grape varieties means that the grapes differ in phenol content and profile, and thus also in colour and taste. Thus, wines produced from different grape varieties may also have a different taste and colour, and according to some authors, the grape genotype may have a significant impact on the profile of phenolic compounds and antioxidant properties of the wine [90]. The content of phenolic compounds in wine depends, among others, on their concentration in the skins, flesh and seeds of the grapes [4] and the total phenolics content of the grapes varies between grape varieties. In the study Van Leeuw [90] showed a significantly lower antioxidant capacity of wine produced from the French *Pinot Noir* grape variety (948 mg/L gallic acid equivalent) compared to wines produced from other grape varieties, for example antioxidant capacity of wine produced from the *Syrah* grape variety is 3476 mg/L gallic acid equivalent), which was associated with differences in the content of individual phenols, especially with significantly lower levels of anthocyanidins and flavonols. On the other hand, wine made from the Italian grape variety *Ancellotta* (3926–4202 mg/L gallic acid equivalent) was characterized by a significantly higher concentration of phenols, especially flavanols, flavonols and anthocyanins 3-O-glycosides (flavanols, flavonols and anthocyanins 3-O-glycosides) than the wines *Rebo* (2262–2409 mg/L gallic acid equivalent), *Nebbiolo* (1756–2323 mg/L gallic acid equivalent), *Barbera* (1319–2360 mg/L gallic acid equivalent) i *Teroldego* (3209-3356 mg/L gallic acid equivalent) varieties [79]. Gomez Gallego et al. [27] analyzed, inter alia, the composition of phenols and the antioxidant properties of two vintages of Spanish red wines produced from the grape varieties *Moravia Dulce*, *Rojal* i *Tortosí*. It was shown that the phenol content was influenced by both the grapevine variety and the vintage year, while the phenol profile was mainly influenced by the grape variety. Among the anthocyanins in wines produced with *Moravia Dulce* and *Tortosí,* malvidin 3-glucoside dominated, and peonidin 3-glucoside dominated in the wine of the *Rojal* variety. Among the flavonols (flavonol), quercetin dominated in *Rojal* and *Tortosí* wines, and myricetin dominated in *Moravia Dulce* wines, while all wines contained large amounts of resveratrol. Chlorogenic, coffee and syringic acids dominated in the composition of phenolic compounds in Brazilian red wines produced from grapes of the *Vitis labrusca* variety [19]. Thus, depending on the grape variety used, wines can also be differentiated in terms of the content of phenolic compounds.

The climatic and soil conditions of the wine-growing area also have a significant influence on the chemical composition of the wine and the phenolic content. Grapes grown in orphan soil have the highest total phenolic and tannins, which influenced the composition of the wine, while grapes grown in aeolian soil have the highest anthocyanin content [95]. The Mediterranean region, where summers are warm and dry and winters cool and wet, are optimal, and therefore the most favourable for wine production, in contrast to the tropical climate, which is characterized by high temperature, rainfall and high humidity. However, climate change is leading to vineyards being planted in upland areas changing the ecosystem, as seen in areas such as western North America [30]. In the study of Brighenti et al. [9] the phenolic content of wines produced in the high mountain regions of southern Brazil at an altitude of 1,400 meters was analyzed as this area has a high accumulation of global solar radiation promoting phenol synthesis in grapes. In the case of white wines, the highest content of polyphenols was found in wine produced from the *Greco di Tufo*, variety, and in the case of red wines - in wine produced from the *Ancellotta* variety [9]. According to other authors, the Italian grape varieties *Ancellotta*, *Rebo*, *Nebbiolo*, *Barbera* and *Teroldego* can be successfully grown in southern Brazil, where the subtropical climate prevails [79].

In the samples of wines from Apulia in southeastern Italy, the amount of phenolic compounds depended largely on their colour, with red wines containing the highest amounts of phenols (23,7–28,0 mg/kg gallic acid) compared to white (2,7–12,5 mg/kg gallic acid) and rosé (5,5–7,4 mg/kg gallic acid) wines. The dominant phenolic compounds in wines were gallic acid, syringic acid and luteolin, as well as hydroxytyrosol, quercetin and resveratrol [69]. In red wines produced in the Canary Islands, quercetin was the dominant phenolic compound, which may be a characteristic element of these wines [72]. Interestingly, Gambelli & Santaroni [24] analyzed the possibility of correlating the concentrations of phenolic compounds with the geographical origin of wine and using the properties of these compounds for wine classification. Wines from the two Italian regions of Apulia and Molise, which differ in environmental conditions, were analyzed. The results showed differences in the concentration levels of individual compounds in the group of flavonols, anthocyanins and phenolic acids, however, the observed differences were not related to the geographical origin of the wines, so it is not possible to identify the geographical origin of the grape wine on the basis of the concentration of phenolic compounds. In the case of fruit wines, an experiment by Klarić et al. [38] showed that blackberry wines from three different Croatian sub-regions can be classified according to the content and composition of phenolic compounds according to their geographical origin.

It is worth adding that the composition of phenolic compounds in wine also depends on the method of grapevine cultivation or fruit ripeness during harvest [63]. Due to the premature harvest of the grapes, the phenolic maturity of the grapes may be lagged behind their technological maturity. Wines made from these grapes may have a lower phenolic content or an unbalanced phenolic composition, which may reduce the overall quality of the wine [2].

THE IMPACT OF WINE PRODUCTION PROCESSES ON PHENOLIC CONTENT

The profile of phenolic compounds in wine depends not only on the concentration of phenolic compounds in grape skins, flesh and seeds, but also depends on the techniques of wine production [4]. Grapes contain significant amounts of water and sugar, which makes them very susceptible to spoilage during storage, even when refrigerated [96]. One of the techniques used to eliminate microorganisms in grapes stored at low temperatures is the use of high hydrostatic pressure or ozone treatment, which prevents spoilage and significantly extends the shelf life of grapes [57]. Fresh grapes can be used for the production of wine, but the grapes have also been previously subjected to dehydration, an example is Tokaj wine, which is made from dried grapes. It is worth noting that depending on the time and drying temperature it can lead to degradation of phenolic compounds in the raw material [94].

In the case of wine made from grapes, the first stage of production is the mechanical separation of the stems from the fruit and the mechanical crushing of the grapes, releasing the juice and pre-fermentation [85]. Then must is heated and it is maceration, in which not only the temperature is important, but also the activity of hydrolytic enzymes, ethanol content, and then the must is mixed [34]. To increase the extraction of anthocyanins, tannins and other phenolic compounds from the grape skins, various techniques can be used, e.g. ultrasound, pulsed electric fields or high hydrostatic pressure, which facilitate the degradation of the grape cell walls and the increased release of these compounds accelerates the maceration process [57]. Pulsed electric fields or high hydrostatic pressure can also be particularly useful in extracting grapes poor in phenolic compounds, so there is no need to mix these grapes with grape varieties richer in phenolic compounds or use enzymes pectolytic [21]. The enzymes added to the must at the maceration stage are mainly pectinases, cellulases and hemicellulases, the so-called pectolytic enzymes degrade pectins into shorter and more soluble molecules in the process of hydrolysis, which facilitates pressing of grapes and extraction of coloured and aromatic compounds [80]. In winemaking, enzymes are used at different stages: pre-fermentation, alcoholic fermentation, post-fermentation and wine maturation, using both natural enzymes that are present in grapes and commercial enzymes, most often produced by the *Aspergillus* species [14].

Maceration is an important process, especially in the production of rosé and red wines, because in this process, mainly tannins and anthocyanins and aromatic substances from grape skins, seeds and pulp are extracted into wines. The different maceration techniques used in red wine production affect the amount and chemical composition of phenols in the wine [10]. Higher maceration temperature increases the extraction of phenolic compounds and enhances the color of red wine, while maceration at lower temperatures before fermentation has a positive effect on the composition of wines, including lower oxidation of anthocyanins and aromatics, and inhibition of the action of undesirable enzymes. Maceration carried out in the temperature range from 10 to 15°C produces red wines with the highest total phenolic and anthocyanin content, as well as with a more intense color and richer aroma [81]. In the study Bayram et al. [5] the effect of the type of maceration on the content of phenolic compounds in red wines was compared, while in classic maceration the must and pomace were macerated and fermented at 24°C for 10 days, in cold maceration at 4–6°C for 96 hours before the process fermentation. It turned out that cold maceration did not increase the content of phenolic compounds in wine, and the content of individual phenolic compounds in wines subjected to classic maceration was higher than in wines subjected to cold maceration [5]. The maceration time affects the extraction efficiency of phenolic compounds from grapes into wine. In the experiment of Ivanova et al. [33] the highest content of phenolic compounds was found in wines produced with 6 days of maceration, with the exception of flavan-3-ols, belonging to the tannins, the highest amounts of which were recorded in wines macerated for 10 days. Casassa et al. [10] reports that anthocyanins, responsible for the colour of red wines, reach their peak of extraction after 4 or 5 days of maceration, and then their level decreases with increasing maceration time. In turn, Sener [81] reports that prolonged maceration also leads to a wine with a stable red colour and a more tart taste.

Rosé wines are also macerated, the method of production of which is similar to the production of red wine, but in rosé wines the grape skins are removed before fermentation, unlike red wines, which ferment with the skins. Maceration of rosé wine moderately reduces the phenolic content of the wine [67]. In the production of white wines, maceration is not used or the process is short (24 hours at a temperature below 20°C), often carried out before fermentation, and the goal is to obtain a more complex taste thanks to the extraction of grape aromas into the must [49]. According to Ružič et al. [75] the use of this process in the production of white wine allows to obtain the content of polyphenols and antioxidant properties similar to red wine. On the other hand, white wines, produced without maceration, contain lower amounts of total phenols compared to red wines, and they are mainly non-flavonoid compounds, concentrated in the pulp, namely hydroxycinnamic acids and their derivatives [59]. In the study Korenika et al. [40] it was observed that the phenolic profile of white wine depends on the maceration time, with the most optimal maceration time being 6 months, because the polyphenol content was the highest and the antioxidant properties were the best, moreover, it was found that the higher the total phenolic content, the higher the antioxidant capacity of white wine. Also Lukić et al. [49] showed that the extended maceration time of white wine increased phenol concentration, color intensity, antioxidant activity. Contradictory results were obtained by Preserova et al. [67], who observed that the maceration of white wine caused a significant reduction in the total phenolics content. Fruit wines are also macerated with commercial enzymes at the early stage of fruit extraction, and then during pressing and clarification [92].

In red wine production, the grape pulp, skins and seeds are kept together after crushing and during all or part of the fermentation process, with the skins not being separated from the juice, unlike in white wine production, where the juice is separated from the peel and then clarified by sedimentation or centrifugation, then yeast is added to the clarified juice to initiate fermentation [85]. Due to the fact that white wine is produced from grape-free must, it contains less polyphenolic compounds compared to red wine made from whole fruit [65]. Piljac et al. [66] observed that white wines contained about 10 times less phenolic compounds than red wines, which is due to the lack of anthocyanins and other pigments present in red wine. The significantly higher content of phenolic compounds in red wines (2082–3184 mg/L gallic acid) also causes their antioxidant activity to be much greater than that of white wines which contains less phenolic compounds (213–277 mg/L gallic acid) [73].

In general, the method of producing fruit wines is similar to the technique of grape wine production, although the extraction of sugars and other compounds from the flesh of some fruit is most problematic, therefore specialized equipment is used for fine grinding the fruit, and then pressing it to squeeze the juice from the finely ground pulp [85]. Interestingly, although the lowest content of phenolic compounds is in raspberries (121 mg phenolics/g fresh weight) compared to bilberry (525 mg phenolics/g fresh weight), lingonberry (652 mg phenolics/g fresh weight) or redcurrant (1400 mg phenolics/g fresh weight), the extraction of phenols into wine from these fruits is the highest due to the thin skin [62]. On the other hand, in currants, which have a thick skin, the percentage of extraction of bioactive compounds from fruit is the lowest [84].

The next stage of wine production is fermentation, during which yeast, most often *Saccharomyces cerevisiae*, transforms the sugars contained in the juice into ethyl alcohol and carbon dioxide [85] and produces various by-products, e.g. carbonyl compounds, alcohols, esters, acids and acetals that influence the quality of the finished wine [82]. Often, sulphur dioxide is added to the must before fermentation, which has an antibacterial and antioxidant effect, and also increases the transfer of phenolic compounds to the must [33, 57]. However, due to the negative effects of sulphur dioxide on health (diarrhea, urticaria and abdominal pain), modern techniques are currently being used, such as pulsed electric fields, high hydrostatic pressure, but also UV irradiation or e-beam irradiation that make it possible to produce wine without the addition of sulphur dioxide [57]. It is also possible to produce red wine in an organic system, so without the addition of sulphur dioxide, and in terms of the total content of polyphenols and flavonoids, phenol profile and antioxidant activity, such wine does not differ from conventionally produced wine [25].

Fermentation at a lower temperature of 10-15°C has an unfavourable effect on yeast growth, leading to an extended fermentation time and the risk of its inhibition, while a higher temperature allows faster growth of yeast and its use of sugar, which promotes the formation of ethyl alcohol [97]. Liu et al. [46] showed that high fermentation temperature (25–30°C) not only accelerated sugar utilization and alcohol formation, but also increased the content of phenols, tannins and flavonoids in red wine. Similarly, in the production of rosé wines, fermentation with the use of yeast caused a rapid increase in the content of phenolic compounds, while in the production of white wine it did not change the content of phenols [30, 67]. White wine fermentation is carried out using exogenous yeast in stainless steel tanks at relatively low temperature between 12 and 18°C [49].

Fruit wines are made from a mash or fruit juice that is fermented, and may need to add sugar to stimulate the fermentation process when the fruit does not contain enough natural sugar to ferment by itself in the presence of yeast. Some fruits, such as cherries, raspberries, strawberries, and pineapples, contain significant amounts of acids, which may require the addition of sucrose to counteract the acidity of the fruit, and water to dilute the excess acid [77]. The higher the sugar content, the higher the amount of alcohol produced, which additionally facilitates the transfer of phenols to fruit wine [16]. One of the most widespread non-grape fruit wines is apple wine, which is made from fermented apples. As in the production of grape wines, apple must is fermented, with the optimal temperature ranging from 15 to 18°C, after prior addition of sulfur dioxide [85]. Alcoholic fermentation of apples does not affect the overall content of phenolic compounds in the resulting apple wine, which means that the level of phenolic compounds of the original clarified apple juice is maintained, while the content of some phenols: caffeic acid and catechin increases [60]. After fermentation, the apple wine is filtered, clarified and then pasteurized at 60°C for about 20-30 minutes [85]. In the case of raspberry, blackberry, blueberry, cherry and black chokeberry wines, fermentation is carried out at a temperature of about 20°C for 7–10 days [16]. Due to the differences in the composition of the fruit used in the production of fruit wines, the yeast strain used for fermentation must be adapted to different environments, e.g. sugar concentration, the presence of organic acids, etc. However, most often the same strain is used as in wine production grape, namely strains of *Saccharomyces cerevisiae* [92].

The next stage is wine clarification using special clarifying agents, eg enzymes, gelatin, bentonite, etc., while the wine clarification techniques do not significantly affect the profile of phenolic compounds or the antioxidant activity of wines [93]. Although it is indicated that the addition of bentonite to the clarification of white and rosé wine significantly reduces the total phenol content [67]. The clarification of fruit wine is the same as that of grape wine, and pasteurization is carried out before bottling the wine, with or without preservatives [92].

The next process is filtration to obtain clear wine without organoleptic changes, e.g. using membrane filtration, which allows simultaneous clarification, filtration and sterilization of the wine, and in addition does not change the antioxidant activity of the wine [93].

Then the grape wine is stored in stainless steel vessels or in oak barrels [85], while maturing and aging in oak wood wine barrels, polyphenolic compounds (tannins) from oak wood, especially ellagitanin C-glucoside, which take part in oxidation reactions, affecting the organoleptic properties of wine, including for its tartness [70]. The wines mature for at least 12 months in oak barrels and another 12 months in a bottle [3]. During maturation in a barrel or in a bottle, polymerization and condensation reactions take place, which modify the composition of the wine and its quality features [33]. Arnous et al. [3] observed that ripening red wines are characterized by a different polyphenolic composition compared to young wines, mainly due to the fact that phenolic compounds, especially anthocyanins, undergo polymerization reactions, but also oxidation, hydrolysis and other changes that may take place during aging. Bimpilas et al. [6] noted that when wine is stored for 12 months, the content of anthocyanins tenfold decrease as they participate in polymerization reactions, and there is also a slight decrease in the total amount of flavonols (from 161 to ~140 mg/L quercetin equivalent for Merlot wine and from 193 to ~150 mg/L quercetin equivalent for Syrah wine). Additionally, the amount of glycosylated flavonols, which are subject to enzymatic hydrolysis, is reduced. However, these reactions do not significantly affect the total polyphenol content of the wine. Similarly, Ivanova et al. [33] showed that during wine storage, anthocyanin content decreases rapidly, especially in wines that have been macerated briefly (from 54 to 84%) and those that have been stored at higher temperatures (300-850 mg/L total anthocyanin) compared to those that have been stored at lower temperatures (50-400 mg/L total anthocyanin). Peri et al. [64] found no significant changes in total phenolic content, total flavonoid content and total antioxidant capacity in the red wine maturation period, however, a significant decrease in anthocyanin content was noted.

Fruit wines also undergo a maturing process, during which the aroma changes are observed, the process takes standardly 6 months, but may be extended to 2-3 years in order to obtain a clear wine with a mild taste [41].

CONCLUSION

The content and profile of phenolic compounds in grape wine depends on many factors: grape variety, location of the vineyard, cultivation system, climate, soil type, grapevine cultivation method, harvest time, as well as the production and storage process of the finished product. The production of grape wine involves several technological processes that can be modified depending on the type of wine produced. Based on the literature data, it can be concluded that pressing, maceration and fermentation of the must increase the total content of phenolic compounds in wines, clarification and filtration generally do not significantly affect the phenolic content of wine, while wine maturation and storage mainly significantly reduces the anthocyanin content, but also favourably shapes the taste and aroma thanks to the processes of polymerization and condensation. The production of fruit wines is similar to the method of producing grape wine, therefore the technological processes will similarly affect the content and profile of phenols in these wines, although it depends mainly on the raw material used. The amount of research on the influence of various factors on the level of phenols in fruit wines is insufficient in contrast to numerous studies on viticulture and the characteristics of grape wines. Phenolic compounds present in both grape and fruit wines are characterized by a wide spectrum of biological activity, demonstrating antioxidant, anti-inflammatory, anticancer and cardioprotective properties, therefore it seems that fruit wines can be an alternative to grape wine.

PODSUMOWANIE

Zawartość i profil związków fenolowych w winie gronowym zależy od wielu czynników: odmiany winorośli, lokalizacji winnicy, systemu uprawy, klimatu, typu gleby, sposobu uprawy winorośli, terminu zbioru, a także od procesu produkcji i przechowywania gotowego produktu. Produkcja wina gronowego obejmuje kilka procesów technologicznych, które mogą być modyfikowane w zależności od rodzaju produkowanego wina. Na podstawie danych literaturowych można stwierdzić, że tłoczenie, maceracja i fermentacja moszczu zwiększają ogólną zawartość związków fenolowych w winach, klarowanie i filtracja generalnie nie wpływają w sposób istotny na zawartość fenoli w winie, natomiast dojrzewanie i przechowywanie wina wpływa przede wszystkim na znaczące zmniejszenie zawartości antocyjanów, ale także korzystnie kształtuje smak i aromat dzięki zachodzącym procesom polimeryzacji i kondensacji. Produkcja win owocowych jest zbliżona do sposobu wytwarzania wina gronowego, zatem procesy technologiczne w podobny sposób będą wpływały na zawartość i profil fenoli w tych winach, choć jest on zależny głównie od zastosowanego surowca. Liczba badań dotyczących wpływu różnych czynników na poziom fenoli w winach owocowych jest niedostateczna w przeciwieństwie do licznych badań dotyczących uprawy winorośli i charakterystyki win gronowych. Związki fenolowe obecne zarówno w winach gronowych, jak i owocowych charakteryzują się szerokim spektrum działania biologicznego, wykazując właściwości przeciwutleniające, przeciwzapalne, przeciwnowotworowe czy kardioprotekcyjne, zatem wydaje się, że wina owocowe mogą być alternatywą dla wina gronowego.

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