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Circular economy in food industry

ABSTRACT

The concept of the circular economy goes beyond the outdated idea of the linear economy, which involves the uncontrolled exploitation of natural resources, and the material flows from the factory through the user to the landfill. In the circular economy, the circle product - waste - product is closed. It is expected from the industry to function as a natural eco-system, and waste from one industry becomes a raw material to another industry, i.e. to stimulate circulation, from which the term circular originates. The circular economy is a general term that encompasses all activities that reduce, reuse, and recycle materials in the processes of production, distribution, and consumption. Taking into account the projections for population growth on Earth, the food industry is expected to increase production, which inevitably carries an increase in the amount of generated waste. Organic components of vegetable waste are of interest for further use because they contain large quantities of highly valuable molecules. This paper aimed to show that waste from the food industry is not waste but a raw material that can be incorporated into other processes, which are the basic principles of circular economy - regeneration and circulation. The wine industry, as a major industry for the grape as raw material, creates large quantities of such waste. In the literature review are provided various innovative solutions that show what to do next with wine by-products, especially grape hush. Besides using in the industry of strong drinks, through composting or as a forage supplement, new solutions are presented. They are: the hush as a significant bioenergy source; the use of the most important substances from the hush, such as polyphenolic compounds, dietary fiber, tartaric acid, oils; the hush as a raw material for the production of biofuels, enzymes, biosurfactants, etc.

Keywords: Circular economy; food industry; wine industry; pomace.

1. INTRODUCTION - BASIC PRINCIPLES OF CIRCULAR ECONOMY

The term economy originates from the Greek word *oikonomikos* and is a compound noun that originally means - the laws of household management. Since the beginning of industrialization until the end of the XX and the beginning of the XXI century, the economy can be considered as linear. Raw materials were available and cheap, and the question of limited natural resources was not raised. However, with the growth of production, the amount of waste also increased and people began to see the negative aspect of the industrial development on the environment. In addition to the

direct influence of industry, the transition from the rural to the urban way of life and the development of consumerism also have a great impact. People live by the principle: take - use - dispose, without thinking about what happens next with that waste [1,2].

With the amount of waste as well as energy demand increasing, and available natural resources limited, the usage of waste has become one of the main topics for scientists around the world. By reducing the amount of waste, we are moving towards cleaner production, which is considered a transitional phase towards zero emissions.

The concept of cleaner production, as well as the Zero Emission Concept implies a developed network between industries, their grouping and close mutual cooperation. Industries themselves are expected to modify their processes to make the most of their resources, alone or in collaboration with a network of industries, as waste can be a resource if put in the right place.

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Circular economy can be defined as an industrial system that is renewable or regenerative with intent or design, with the aim of eliminating waste through superior design of materials, products, systems and business models [3,4], or can be defined as an economic strategy proposing innovative ways for transformation of the currently

predominant linear system and achieving economic sustainability with material savings [5]. In general, circular economy is a general term that encompasses all activities that reduce, reuse and recycle materials in the processes of production, distribution and consumption [6].

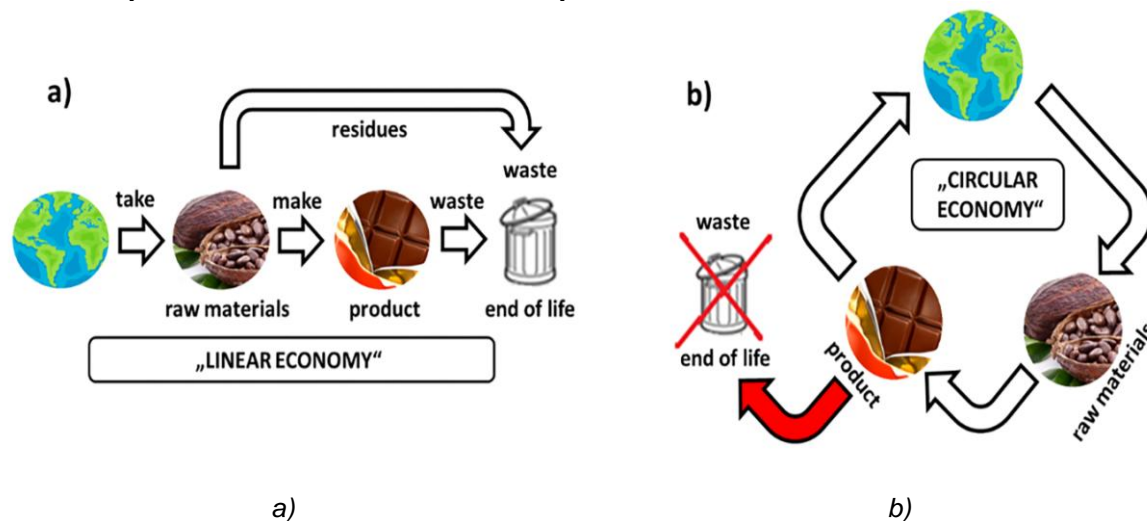


Figure 1. a) Basic principle of linear economy; b) basic principle of circular economy

Slika 1. a) Osnovni princip linearne ekonomije; b) osnovni princip cirkularne ekonomije

The increasingly accepted concept of circular economy in this way goes beyond the outdated concepts of linear economy, which implies the uncontrolled exploitation of natural resources and the flow of materials from the factory through the user to the landfill [2]. This can be achieved by reducing harmful emissions, replacing non-renewable energy sources with renewable ones, thus closing the circle: *product - waste - product*. Thus, the industry is expected to function as a natural ecosystem and that waste from one industry (*output*) becomes a raw material in another (*input*), i.e. to imitate circulation, whence the name *circular* comes from [1].

The approach that involves joint action and *the industrial cluster approach* is something that is striven for. However, a number of issues arise, such as the appropriate size of the cluster, and then there is a limiting factor - a change in technology. How much can the existing technology of a company be changed in order to meet all the requirements, without the change having a negative impact on the company itself, etc.?

The concept of circular economy can be applied to small, medium and large enterprises. In practice, however, environmental improvements are more difficult to achieve in small and medium-sized enterprises due to limited human and material resources. Because of this, merging

companies and acting together is the only way to make progress, regardless of the previously mentioned doubts.

According to the previous definitions, the goal is that industrial production based on the circular economy, in addition to its positive impact on the environment, also contributes to economic growth.

The objectives of the paper are to, using circular economics, perform [7]:

1. identification, discussion and development of various definitions that facilitate the usage of new literature;
2. proposing an initial research approach where research on the circular economy can be conducted.

Circular economy has another great advantage - it is not reserved only for the rich countries of the West. For example, China was the first country in the world to adopt a law on the implementation of the circular economy in 2008, followed by others [8]. The European Union has created a package on the circular economy by extending earlier directives on waste management. The ten-year development strategy (2010-2020) of Europe 2020, which was adopted after the global economic crisis in 2008, mentions the transition from a linear to a circular (circular) economy as one of the EU's development priorities [2].

Based on Germany's many years of experience in introducing a circular economy, 5 phases in the process of improving the waste management system have been defined [9]:

Phase 1 – disposal of waste in uncontrolled landfills,

Phase 2 – reliable waste collection and landfill improvement,

Phase 3 – introduction of separate waste collection and its sorting,

Phase 4 – improvement of the recycling industry,

Phase 5 – circular economy - waste as a material and energy resource.

As far as Serbia is concerned, the recommendations of the European Commission on the circular economy have been accepted, and amendments to the laws in the field of environmental protection have been adopted, including amendments to the Law on Waste Management. The National Strategy for Sustainable Development for the Republic of Serbia was adopted in 2008 and was valid until 2017. Guidelines for further action in the field of sustainable development are given here. It is important that such strategies do not remain just a dead letter, because, as a consequence of the industry based only on a linear economy, Serbia today has 3,500 illegal landfills and only 8 sanitary regional landfills. Only 5-7% of waste is recycled, while at the annual level material worth of 50 million euros is disposed of in over than 150 unsanitary landfills [9].

The aim of these measures is primarily the prevention of waste, reduction of harmful substances in it, enabling the return of products to the life cycle after it becomes waste, improving the volume as well as the quality of recycling, establishing a system of separate waste collection, introducing measures to reduce biodegradable waste at landfills by encouraging composting and anaerobic digestion.

At the state level, but also at the level of the European Union, as well as the rest of the world, discussions on this topic are more frequent, but they are still at the level of concepts and examples from practice are few. More detailed analyzes of this concept are needed, an even deeper theoretical basis, but also its practical application in industry.

2. VALORIZATION OF WASTE AND BY-PRODUCTS IN THE FOOD INDUSTRY

The growing production of food that is necessary to meet the needs of a growing number of people in the world involves serious

environmental issues. Problems that can arise in food processing are related to energy and waste management. Large amounts of waste generated in the food industry raise important issues related to management problems, both from an economic and environmental point of view [10]. At the end of the seventies of the XX century, the first researches began and the first results, which were focused on the reduction of waste and by-products in the food industry, were obtained. All these researches were aimed at valorization of waste from the food industry with the idea of making a profit in the future by using waste and by-products [8,11]. For example, it is necessary to take into account that the generated plant and animal material is prone to microbial spoilage. Such facts limit further valorization, while production alternatives such as drying or storage have economic constraints that limit their application [8]. Therefore, according to van der Goot et al., [12], the reduction of waste production is influenced by the improvement of the management structure and the quality of monitoring in food production chains.

In many organizations, the boundary between waste and by-products is not fixed. According to Santana-Méridas et al. [13], a waste directive has been established, distinguishing between so-called *differentiating waste* (material discarded by the holder), *production residue* (material that is not intentionally produced, which does not have to be strictly, but can be declared as waste) and *by-products* (residue that can be used directly without further processing). According to Jasch, by-products are created during the production process of the main product and they are not the primary goal of production [14], while Galanakis defines by-products as substrates separated from the food production process where functional components can be used, thus facilitating the development of new high quality products on the market [15]. By-products from food production can be generally divided into two groups, depending on whether they come from food of plant or animal origin [16].

The production of waste and by-products from food follows the entire *Food Life Cycle*, from agriculture through industrial production, food processing and sales, all the way to household consumption [10]. In developed countries, 42% of food waste is generated in households, 39% is lost in industrial food production, 14% is generated in food service sectors and 5% is generated in retail chains and during distribution [10]. Waste and by-products have great potential to be reused through various production systems. Given the limitations in the industry, there is a great tendency towards the possibility of using by-products and the usage of essential food ingredients, because they can be an

important source of compounds that can partially or completely replace certain raw materials. The goal is to reduce the amount of waste through an adequately developed production strategy, and then to define the principle according to which any generated waste and by-products can be used in the production of other food or non-food products. Therefore, the implementation and realization of various initiatives at the industrial level leads to achieving maximum waste utilization or *Zero Waste to Landfill*. Industrial concepts of ecology such as the concept of *Cradle to Cradle* and the circular economy can be considered as the leading principles of ecological innovation, having in mind the so-called *zero waste economy* where waste serves as a raw material for new products and applications [10].

However, in order for this "Zero Waste" practice to be adequately implemented, the principle of the waste management hierarchy is very important, as shown in Fig. 2 [17].

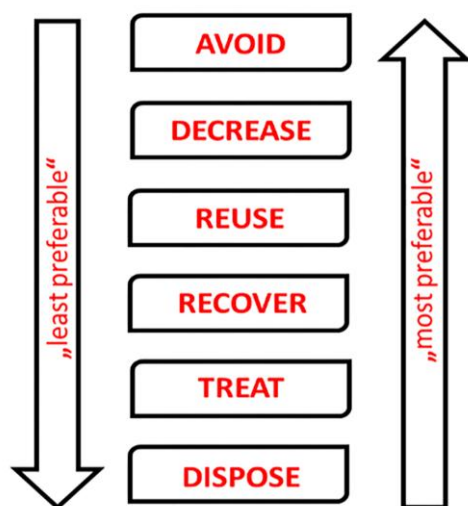


Figure 2. Hierarchy of food waste management (adapted from Kosseva, 2011) [17]

Slika 2. Hijerarhija upravljanja otpadom iz hrane (prilagođeno iz Kosseva, 2011) [17]

This principle of management, the so-called *Green Production Processes* development can be achieved by:

- *short-term goals*, that include the reduction of waste through the reduction and recycling of valuable substances, by-products and residues with reduced both emissions and risks as a final outcome,
- *medium-term goals*, that include the development of an efficient production process, thus increasing the value of by-products,

- *long-term goals*, that include successive applications of organic production, thus developing "innovative products" (eg functional food), thus opening opportunities for new markets and meeting green productivity goals [17,18].

2.1. Sources and characterization of food waste

Significant amounts of waste are generated annually in food production chains that are necessary to be exploited urgently [16]. The food industry produces significant amounts of waste which include: fruit and vegetables leftovers, discarded items, molasses and flakes from sugar refining, bones, blood and skin from meat and fish processing, leftovers from wineries, distilleries and breweries, waste from the dairy industry such as for example whey, wastewater from washing, blanching and cooling operations [19]. Most of the waste in the food industry is less hazardous waste because of its organic origin, however, it can also negatively affect on the quality of the environment. Waste in the food industry is generated in various sectors along the production chain, from farms, packaging / processing, transport / distribution, retail, service and households, with around 18% of waste estimated to come from food processing and packaging as a result of necessary operations. such as washing, peeling, seed removal, separation, etc. [16].

By exploiting the by-products of the food industry, the significance can be multiple. With adequate waste treatment, it can be used in the form of bioabsorbents, additives, new products that include functional food and bioactive ingredients, animal food, microorganism growth substrate, fertilizer materials after composting or as energy sources, for biofuel production (bio-hydrogen, bio-diesel) [8,17,20]. Value-added products produced from waste in the food industry primarily include animal food, single-cell protein (SCP) and other fermented edible products such as bakery yeast, organic acids, amino acids, enzymes (lipases, amylases, cellulases), flavoring compounds, colorants, bacteriocins (from the culture of *Lactobacillus lactis*), microbial gums and polysaccharides [21]. According to Galanakis [15], food waste represents cheap source of important components, which, with adequate separation, can serve as functional additives.

One of the great challenges that contributes to increasing valorization and profitability is the search for new bioactive compounds and the usage of valuable nutritional and functional ingredients present in by-products such as: polysaccharides, vitamins, dietary fiber, bioactive components, etc. [8].

Through a detailed review of the literature, a large number of authors present the possibilities, feasibility and limitations that are based on the utilization of food waste, with the aim of transforming food waste into resources for the production of new products using eco-innovative approaches.

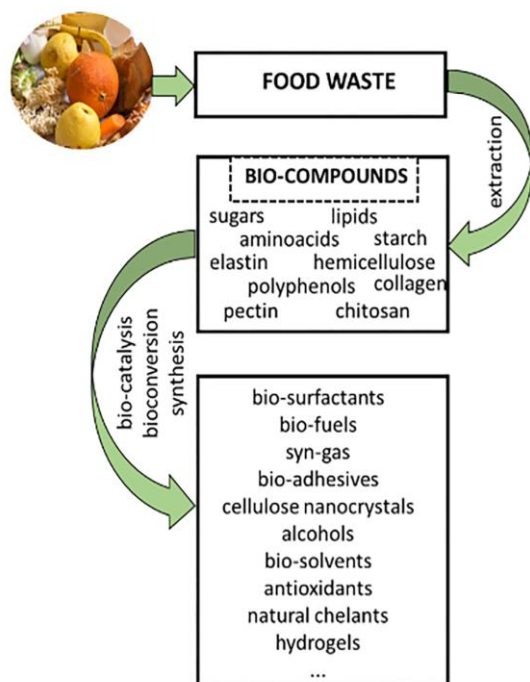


Figure 3 Bio-compounds present in the waste of food industry and some their potential valorisations and further applications (adapted from Lin et al. [22])

Slika 3. Bio-komponente prisutne u otpadu iz prehrambene industrije i neke od mogućnosti njihove valorizacije i dalje primene (prilagođeno iz Lin i saradnika [22])

2.2. Utilization of multifunctional and high-value food ingredients obtained from waste of plant origin

Large quantities of by-products of plant origin are produced every day, and their disposal in landfills has a very negative impact on the environment. In the food industry, large amounts of waste are generated from fruits and vegetables such as potato skins and apple skins [23], apple and grape pomace [24], from cereals such as rice bran [25], wheat bran and by-products from oat grinding [16], wastes such as e.g. residues of malt, hops, molasses from sugar beet production [23], residues of sunflower seeds [24] and soybean waste (okara) [26]. According to Kossev [17], waste

from the fruit and vegetable processing industry, liquid dark colored waste juice from the industrial processing of olive oil, ie waste from the fermentation industries, contains large amounts of suspended matters, organic components and shows high values of biological (BOC or BPK on serbian) and chemical oxygen consumption (COC or HPK on serbian).

However, organic components of waste contain significant amounts of high-value molecules such as sugars, hemicellulose, cellulose, lignin, phenols, organic acids [17]. In addition to the usual procedures such as waste disposal, ie usage of waste as animal food or application for fertilization / composting, there is a need to minimize waste generation through better organization of the production process which will result in the creation of innovative and industrially important metabolites and products. Some examples of important metabolites from plant waste that can be used are: flavors (produced by bioconversion of waste material or solid-state fermentation), pectin and gelling agents, dietary fiber, (matrices for dyes, aromatic components and antioxidants, or their application in the industrial production of bread and beverages), effective and cheap bioadsorbents (which can be easily desorbed and biodegraded after use), produced enzymes, polysaccharides, organic acids, pigments, polyphenols, ethanol, which are described in more detail in Chapter 3 [17].

3. UTILIZATION OF BY-PRODUCTS FROM WINE PRODUCTION FROM THE GRAPE POMACE

Grapes represent one of the leading fruit crops in the world. In addition to the fact that grapes can be used in the production of certain food products such as juices, jams, jellies or can be used as raw, almost three quarters of the total annual production is used in the wine industry for wine production [27]., Between 7 and 8 liters of wine in average is received from 10 kg of grapes. When it comes to brandy, 10-15 kg of fruit is needed to get one liter, depending on the type of fruit, and even up to 20 kg is needed for raspberry brandy. However, the production of white and red wines generates significant amounts of solid organic waste such as pomace and grape stalks. Grape pomace (kom, drop or trop in Serbian) is a form of biomass which, together with other organic residues from wine production and residues from vineyards such as grape stalks, is considered a typical waste product [28].

Pomace is a dominant by-product from the wine industry that contains pulp residues, skin,

seeds, stalks and comprises about 25% of the total mass of grapes processed in production [27,29,30], and is formed as a result of pressing and/or fermentation processes in the wine industry, while the quality and quantity of the produced pomace vary depending on the size of the winery and the applied technological procedure, as shown in Fig. 4 [28].

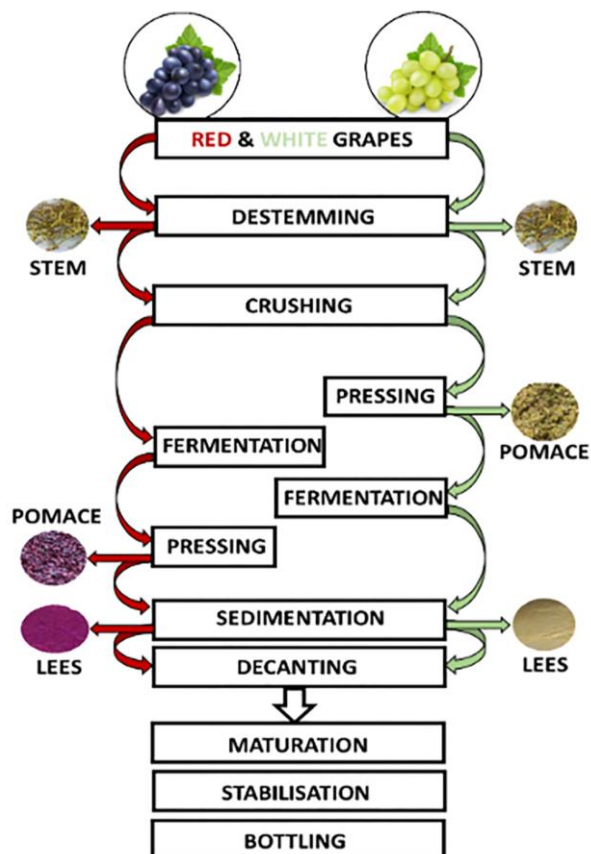


Figure 4. Scheme of generating grape and wine by-products (stem, pomace, skin, seed and lees), during the production of red and white wines (adapted from Muhlack et al. [28])

Slika 4. Shema generisanja nus-proizvoda grožđa/vina (peteljka, komina, pokožica, semenka, talog), tokom proizvodnje crvenih i belih vina (prilagođeno iz Muhlack i saradnika [28])

In addition to the pomace, additional solid waste from the wine industry consists of sediments from clarification processes and sediment obtained after decantation, which are basically extinct yeasts [31]. In the production of red wine, grape juice (must) and pomace are fermented together, while in the production of white wines, must is separated from the pomace by pressing and only must is fermented [32].

Precisely because of these different production processes, white grape pomace contains more pulp and sugar residues [33].

According to the report by Hixson et al. [34], fresh white grape pomace has up to 38% glucose and fructose (expressed on dry weight), while red grape pomace after the production process contains about 1% glucose and fructose.

Although the pomace is most commonly used to make the pomace brandy, it is only one of the options for using the pomace, leaving a dry matter that can be used. Fruit growers and winegrowers, especially if they use their own fruit to make wine and brandy, should seriously consider other options for using the pomace. This also applies to those who buy fruit as a raw material, because the rest of the production can be used to make more products that can bring more profit.

Annually, millions of tons of pomace are generated which represents a great challenge for large wine companies and producers, considering the increasingly strict rules that apply to waste disposal [28].

In recent years, ecological awareness has been developed in developed wine-growing and wine-producing areas with the aim of protecting the environment, thus striving for the development of improved technologies for pomace treatment, and the pressure within the relevant sectors to implement plans based on adequate and sustainable disposal of this waste is increasing [28]. An example is Spain, where government gives wine companies three alternatives for pomace management: recycling, valorisation or disposal, with large fees being charged for pomace disposal, thus encouraging companies to use other more useful alternatives [31].

The potential use of by-products from grape processing is not only related to solving environmental problems, but also provides opportunities to improve food quality and develop high-value ingredients and products [35], as shown in Fig. 5.

Many studies indicate the possibility of using high - value products such as ethanol, organic acids (tartrates, malates), hydrocolloids, dietary fiber [24], sugars [28,34], phenolic components, antioxidants, [36-38] from the skin, as well as the usage of seed oil [39,40], while the stalks contain high concentrations of tannins [41]. According to the tendency to use these natural compounds, possible applications of grape pomace are numerous, such as functional food, biosurfactants, cosmetics, pharmaceuticals and supplements [32,42,43].

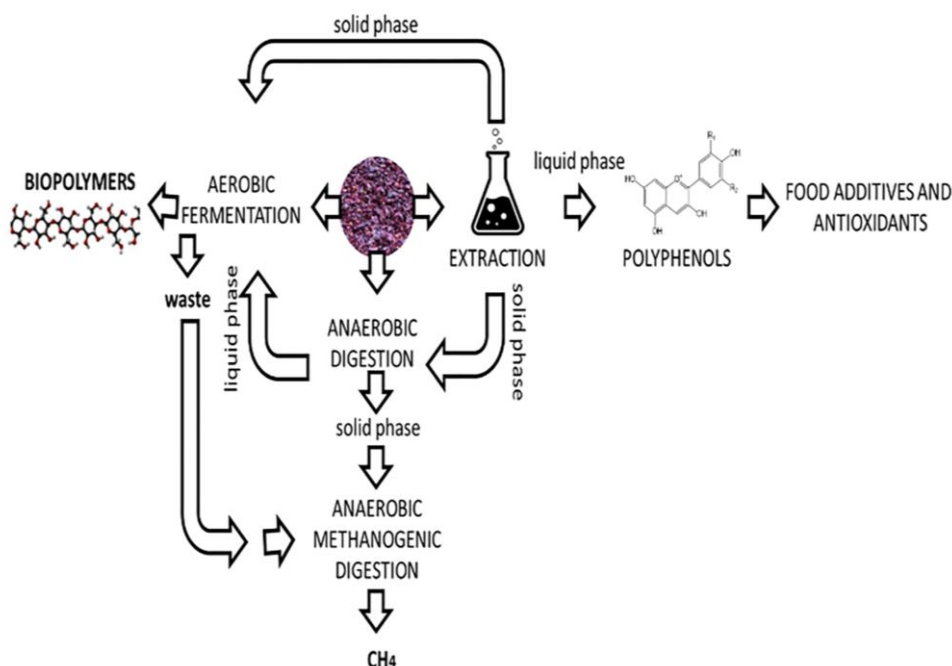


Figure 5. The scheme of obtaining polyphenols, biopolymers, and methane from the grape pomace (adapted from Martinez et al. [35])

Slika 5. Shema dobijana polifenola, biopolimera i metana iz komine grožđa (prilagođeno iz Martinez i saradnika [35])

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According to Rivera et al. [44] grape pomace can be used in the production of biosurfactants that have important applications in the food industry due to their emulsifying properties. However, due to the accumulation of large amounts of pomace which has a high moisture content, this by-product is prone to decay [45]. For these reasons, grape pomace should be processed immediately or converted into a stable dehydrated product [46], having in mind that the process of drying and storage of dried material over a long period of time leads to significant losses of essential components, especially phenolic compounds [47]. It should be

also considered that even after certain treatments, such as extraction of high-value components from pomace, tartrate or ethanol, streams of solid residues remain, which must subsequently be adequately removed to prevent groundwater pollution and the spread of unpleasant odors [28].

Also, pomace and other residues from the wine industry can be recycled as compost [48-50] or used as livestock food [32].

Pomace as an organic fertilizer

Pomace can be an excellent organic fertilizer, although it is not the richest in terms of nutrients that are present in it. In addition, it is excellent for improving soil structure. Although there is a practice of leaving the pomace in the ground for the purpose of fertilization, composting has multiple advantages, primarily due to the mineral enrichment of the fertilizer.

Making compost from pomace also includes adding other crop residues. This certainly includes withered leaves and pruning residues. Sawdust, hay and straw are also recommended, and the remains that are infected should be burned as a precaution.

The goal of adding other plant residues is to raise the levels of NPK (nitrogen, phosphorus and potassium) which are not present in high concentration in pomace. However, there is a significant difference between different types of fruit and pomace from wine and brandy. For example, white grape pomace has a much higher concentration of nitrogen and sugar than red grape pomace from the standard wine production process. The reason for that is that the red grape pomace is left to ferment together with the fruit juice, while that is not the case with white grapes and white wine production.

When making compost, special attention should be paid to the looseness of the material to be composted. Considering the physical-mechanical properties of the pomace, it is necessary to add substances that will make the mixture more loose and thus provide needed oxygen for the bacteria. One of the possibilities is to dry the pomace in order to remove excess moisture before composting. Pomace can be mixed with manure and left to burn. In this case, microorganisms from the manure decompose the remnants of fruit production.



Figure 6. Compost made from the pomace
Slika 6. Kompost od komine

Composting waste from the wine industry, however, is an alternative to traditional waste disposal [49].

Pomace as feed

Fruit pomace/pulp rich in cellulose, such as apples, has long been used as livestock food. In the last few years, it has been recommended to feed cattle with grape pomace. One of the reasons for that is the explosion of production in winemaking, which results in a large amount of waste material.

All pomace, in addition to cellulose, is rich in sugars, organic acids, tannins, vitamins, antioxidants and other substances present in fruit. But it should not be forgotten that fermentation yeast can also be found in pomace, especially in the pomace that remains from the production of red wine.

Yeast-containing pomace also contains B-complex vitamins. In combination with other livestock food, an excellent food for fattening cattle is obtained. The reason for this is that yeast, and especially B-complex vitamins, increase the appetite of animals, as well as humans in general. The presence of stones in pomace is also beneficial for animals, especially grape seeds. Of course, it can be combined with other livestock food.

When it comes to the use of pomace as livestock food, the results of scientific research are twofold. While some studies show the positive properties of pomace as a source of condensed tannins that lower the level of methane produced inside animal organisms, other studies suggest that the inclusion of pomace in livestock food may lead to reduction of digestibility.

3.1. Utilization of energy from grape pomace obtained by applying the thermal conversion process

By applying thermal conversion, highly valuable products such as energy (in the form of heat or electricity), coal, transport fuels that have economic significance can be obtained from pomace [51].

Grape pomace can also be used as a significant bioenergy source [52] and for this purpose, several thermochemical processes that allow conversion have been developed, but a number of technical and economic issues arise. Additional factors that can have a major impact are: seasonal availability of biomass, transport and storage logistics, conversion efficiency, and the value of conversion products [53,54] (Fig. 7).

Relevant properties of fuels obtained by conversion from pomace include calorific value (key parameter related to the performance of thermochemical conversion, which refers to the energy content of the raw material), alkaline ratio, fixed carbon to volatile matter ratio, ash composition and moisture content [28].

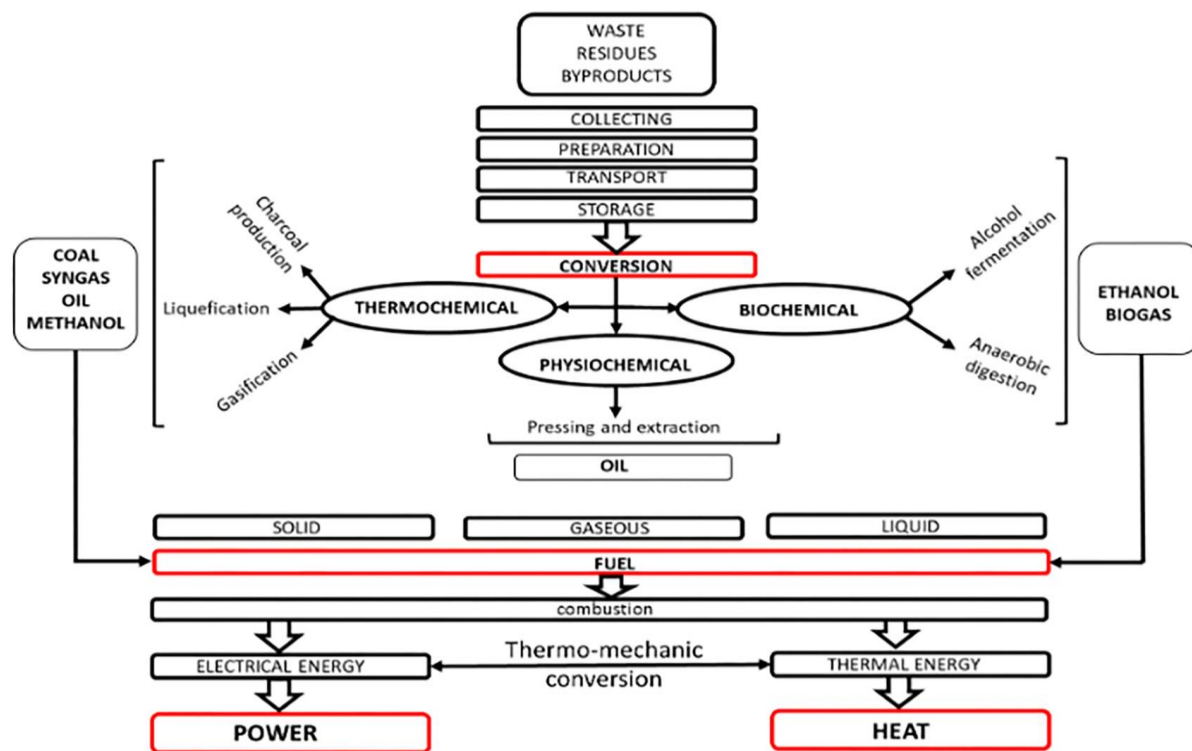


Figure 7. Overview of renewable energy production from organic substrates for example, such as grape pomace (adapted from [54,55])

Slika 7. Pregled proizvodnje obnovljive energije iz organskih supstrata na primer, kao što je komina (prilagođeno iz [54,55])

The calorific values of these fuels are similar to the calorific values of fuels obtained by the conversion of other agricultural and industrial residues (sawdust) [55-58], but also to the calorific values of coal [59]. Biomass with high concentrations of alkali metals, as is the case with grape pomace, is very prone to ash agglomeration and requires an adequate strategy that will ensure the effective conduct of large-scale processes [60]. The moisture content of the raw material is also a very important parameter, because if the raw material is wet, it can negatively affect the energy balance and economic efficiency of thermal conversion of biomass into energy, so water removal is required prior the process [61]. Due to the high moisture content, thermal treatment of pomace by torefaction (thermal pretreatment involving heating the biomass to a temperature of 200-300°C, in an inert gaseous environment) [55,62], hydrothermal carbonization [63], or using solar drying [28] is necessary. Torefaction can be classified depending on the heating temperature as *light* (200-235°C), *mild* (235-275°C) and *severe* (275-300°C) [62]. The effect of torefaction is reflected through the reduction of moisture, which increases the calorific value by reducing the ratio of oxygen:carbon and hydrogen:carbon biomass [55]. Hydrothermal carbonization is a process similar to torefaction that involves low-temperature heating of

biomass at temperatures of 180-250°C [28]. Heating takes place in an aqueous suspension at saturated pressures, making this process ideal for the treatment of highly moist biomass such as grape pomace [63]. The application of hydrothermal carbonization removes most of the non-organic ingredients (alkaline salts) that dissolve in the process water, which significantly reduces the ash content [28].

It is very important to point out that "second generation" biofuels, obtained from waste biomass, are easily converted into energy, thus avoiding the environmental, economic and social impacts associated with production [51]. However, despite numerous studies based on the usage of grape pomace for various applications, it has not been successfully implemented and applied on a larger scale [29].

3.1.1. Combustion, gasification and pyrolysis

There are several technologies available that perform thermal conversion of previously prepared biomass (dry pomace), namely: combustion, gasification and pyrolysis [28]. Depending on the applied technological process, heat and electricity can be produced, ie biofuels such as syngas, coal and biofuels. Syngas and biofuels can be used with additional refining to produce transport fuels such as diesel or high octane gasoline [64-67]. The heat

energy released during biomass combustion can be used to heat a process or a space [68], or it can be used to produce electricity through a steam turbine and generator [69,70]. The usage of grape pomace pellets for heat production is a promising technology from an environmental perspective, given that the main advantage over fossil fuels lies in the reduced contribution to climate change [71]. According to Miranda et al. [57] grape pomace pellets can be used in combustion processes because they show good thermal characteristics, but undesirable values of certain parameters such as ash level and emissions of organic and non-organic pollutants have also been shown. However, it was found that the combination of pomace pellets and oak sawdust (lat. *Quercus pyrenaica*) improves these undesirable parameters without deteriorating the thermal properties.

Studying the combustion characteristics of agricultural and industrial residues, including raw grape pomace, Fernandez et al. [72], suggests that combustion of the pomace in the range of 550°C to 950°C forms fine particles that pose an environmental risk, while TG and DTG studies have shown that after combustion of the pomace almost 10% of the mass remains as ash.

Gasification is a process of partial oxidation of combustible biomass at high temperatures (800-1000°C), in order to form low-calorific flammable gas mixtures (*SynGas*), as well as ash [28,53,73]. *SynGas* mainly contains carbon monoxide, hydrogen, methane and carbon dioxide [74], while the components of the exhaust flue gas include nitrogen, water vapor, hydrocarbons [28]. *SynGas* can be used to generate heat and electricity [58], or by purification it can be used to produce hydrogen gas or liquid transport fuels [65,74]. One of the potential ways to use grape pomace is to transform it into a syngas by gasification process [55]. According to Lapuerta et al. [59], it was concluded

that grape pomace is less efficient for the gasification process compared to other analysed agricultural and wood residues, while co-gasification studies with coal coke showed improved syngas quality when biomass was used. According to Hernandez et al. [58], grapes pomace and other analysed raw materials showed higher quality of produced gas and higher efficiency of gasification compared to coke.

Pyrolysis is the thermal decomposition of biomass under limited conditions at a temperature of about 400-700°C [53,75]. The simplest process of thermochemical conversion of biomass results in a mixture of gases, liquid (tar or bio-oil) and coal [49,67]. According to Arvanitoyannis et al. [47], pyrolysis of wine waste produces fixed carbon, volatile substances, ash, or gases: H₂, CH₄, CO, CO₂. Increasing the pyrolysis temperature of wine waste affects on the increased content of fixed carbon and ash, while the content of volatile substances decreases [49,67]. Bio-oils contain a number of organic compounds including aromatic hydrocarbons, alkanes, phenols, ethers, alcohols [75] and can be used as a raw material for the production of heat and electricity. Coal produced from wine waste at temperatures of 600-700°C is suitable for the production of fuel briquettes, while the naturally porous structure of grape pomace coal can be further improved by gasification with the aim of producing activated carbon that can be used as an adsorbent [49].

3.2. Utilization and extraction of significant high-value ingredients from grape pomace

By-products of plant origin are a significant source of bioactive compounds [24,76], that can be used as natural antioxidants and important ingredients of functional foods [24]. However, most by-products are not currently exploited as a source of bioactive components [76].

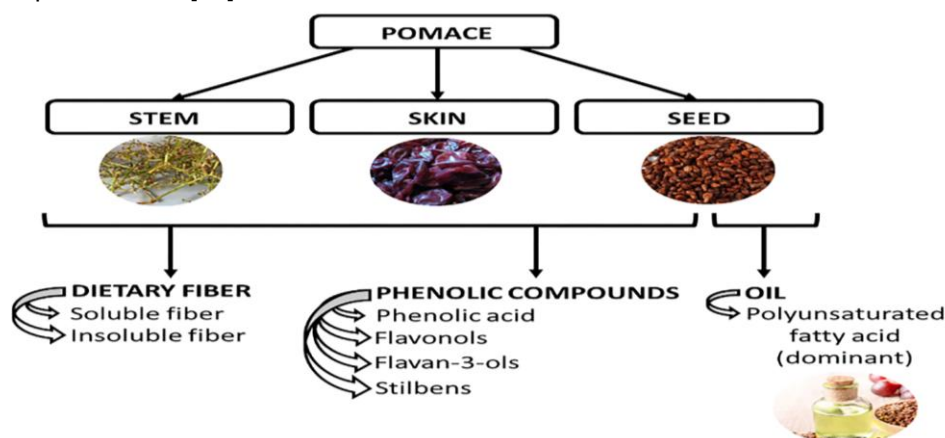


Figure 8. Main grape pomace constituents and individual compounds that can be obtained from them (adapted from Beres et al., 2017 [27])

Slika 8. Glavni konstituenti komine grožđa i pojedine komponente koje mogu biti dobijene iz njih (prilagođeno iz Beres i saradnika, 2017 [27])

Grapes contain significant amounts of various compounds that are partially extracted during wine production [28], but the residual pomace (skin, seeds) represents a good source of high-value components (Fig. 8), such as polyphenols [27,76], pigments, antioxidants [28], dietary fiber [27], sugars, fatty acids [77-79], lignocellulosic material, tartaric acid [28].

Therefore, many studies dealing with by-products from the wine industry are based on the extraction, characterization and utilization of these compounds [27,76,80-83].

3.2.1. Utilization and application of polyphenolic compounds from wine industry by-products

Phenols are defined as secondary metabolites of plants that have one or more aromatic rings substituted with one or more hydroxyl groups within their structure [28,84]. They are usually classified according to their chemical structure and molecular weight into simple phenols (C_6-C_1 and C_6-C_3), flavonoids ($C_6-C_3-C_6$), polymeric compounds (hydrolyzable and condensed tannins, lignin) and other groups of phenols of different structures such as xanthanes, stilbenes, betacyanins, etc. [85]. The skin from the grape pomace is a rich source of phenolic acids such as hydrocinnamic, ferulic acid, or esters of kaftaric and kutaric acid, while the seeds mainly contain gallic and protocatechuic acid [82-86]. In red grape pomace, anthocyanins (malvidin-3-O-glucoside, peonidin-3-glucoside, petunidin-3-glucoside), flavonols, and flavan-3 are the most dominant flavonoids, while others are present in smaller amounts [83-87].

In recent years, a number of extraction techniques have been developed, including pressurised liquid extraction [37,88-90], supercritical CO_2 extraction [38,89], or ultrasonic extraction [79] and microwave extraction [91-95] or extraction by using a pulsating electric field [91], which can be used to extract bioactive components, primarily polyphenols from wine by-products. In general, the most distinctive are supercritical CO_2 extraction, as the most efficient for non-polar compounds such as carotenoids, and pressurised liquid extraction that can be used for extraction of more polar compounds such as polyphenols [24]. Supercritical CO_2 extraction is a new technique for extracting analytes of interest from a solid matrix, which has a number of advantages: it is non-toxic, non-flammable, non-polluting, cheap and there are no traces of residual solvent in the extracted product [92]. Fluid can be considered supercritical when heated above the critical temperature and when it is under pressure above the critical pressure, whereby due to temperature and /or pressure manipulation within

the critical range, the physical extraction properties can be modulated, adjusting the solvent selectivity for each target compound [41]. Pressurised liquid extraction exploits the differential properties of conventional solvents at elevated temperatures and high pressures, affecting the solvents, sample, and interactions between them by improving the extraction of organic analytes from solid samples with the selected solvent [41].

Phenolic components show significant anti-allergic, anti-inflammatory, antimicrobial, cardioprotective and anticancer effects [41]. *In vitro* and *in vivo* studies show that flavonoids present in wine by-products act as effective accumulator of free radicals, and as a result they act as powerful antioxidants and metal chelators [95]. Because of this, wine pomace products are mainly used to enrich food with antioxidants [83]. Grape polyphenols can be used as natural components to prevent oxidation and as functional ingredients of healthy food [96-98]. According to Ferreira et al. [97] grape pomace extract incorporated into edible chitosan films has an improved effect on antioxidant properties and prolongs shelf life, while according to Garcia-Lomilloi González-San Jose [83], pomace can be applied in food industry through the development of spices that have an antioxidant and antimicrobial role.

Due to the high concentrations of bioactive compounds in the obtained grape pomace extracts, very small amounts of these extracts are required for successful application in food systems (Tab. 1).

Extracted anthocyanins from pomace in the form of a commercial product "enocyanin", which has excellent properties for coloring food products, have found application in various matrices such as dairy desserts, ice creams, beverages, juices and other products [24,83]. However, in addition to all the above possibilities of using phenolic compounds, it should be taken into account that during food processing phenolic compounds can be degraded, especially during processes where high temperature is applied [99]. Based on the previously presented facts, several categories of food that can be successfully enriched with phenols from wine pomace are presented (Tab. 1).

There are major global brands that claim to use polyphenols, mainly resveratrol from grapes, such as: "100 Natural", "Nature's Way", "Maximum Strength", "GrapeSeedRich". These products confirm the potential of bioactive compounds extracted from grapes and grape by-products [27].

According to Xu et al. [100], the use of pomace extract reduces the formation of acrylamide during Mylard reactions, indicating another possibility of using waste wine pomace.

Table 1. Food products enriched/fortified with powder, flour or extracts of grape by-products (whole pomace, skin and seed), which known as source of highly valuable compounds (selection from Reference [83])

Tabela 1. Prehrambeni proizvodi obogaćeni prahom, brašnom ili ekstraktom iz nus-proizvoda prerade grožđa (cela komina, pokožica i semenka), koji u poznati kao izvor visoko vrednih komponenti (izdvojeno iz literature [83])

Food products (cereals and dairy products)	Grape by-products (pomace) and its constituents (seed and skin)		Aim of study/improvements	Reference
	Products fortified with	Source of bio-compounds		
Breads and dough	Grape seed flour	Phenolic compounds	Physical, sensory and textural properties	[104]
Breads and dough	Grape seed powder	Phenolic compounds; dietary fiber; fat	Physicochemical and rheological properties	[105]
Bread	Grape seed	Phenolic compounds (especially gallic acid and catechin)	Physical and antioxidant properties	[106]
White bread	Grape pomace	Polyphenols and dietary fiber	Physicochemical, antioxidants, nutritional and sensory properties	[107]
Rye bread	Grape by-products	Soluble and insoluble dietary fibre; phenolic compounds	Antioxidant, rheological and sensory properties	[108]
Wheat biscuits	White grape pomace	Phenolic compounds and dietary fibre	Rheological, nutraceutical, physical and sensory properties	[109]
Biscuit/cookies	Defatted grape seed powder	Phenolic compounds	Physicochemical, antioxidant and sensory properties	[110]
Muffins	Lyophilized grape by-products (skin powder)	Phenolic compounds	Nutritional value, sensory properties and reduce formation of CML	[111]
„breakfast extruded cereals“	Grape peel and seed flour	Phenolic compounds and dietary fibres	Chemical and physical characterization, sensory properties	[112]
Breads, muffins, brownies	Red and white grape pomace	Phenolic compounds and dietary fibres	Physicochemical, nutritional, antioxidant and sensory properties	[113]
Cereal bars, pancakes and noodles	Grape seed flour	Phenolic compounds	Antioxidants properties	[114]
Fermented milk (novel functional product)	Phenolic extract from grape pomace	Phenolic compounds	Antioxidant and sensory properties	[115]
Full-fat and non-fat yoghurts	Grape seed extracts	Phenolic compounds	Antiradical and antioxidant activity	[116]
Yogurt	Grape skin flours	Phenolic compounds and fibres	Physicochemical, microbiological and sensory properties	[117]
Yogurt and salad dressing	Dries whole pomace powder	Phenolic compounds and dietary fibre	Nutritional value and improving storability	[118]
Semi-hard and hard cheeses	Grape pomace powder	Phenolic compounds	Physicochemical, nutritional and antioxidant properties	[119]

Grape pomace extracts can also be successfully used in food preservation as an effective antibacterial agent against various bacterial genera. According to Xu et al. [101], the examined grape pomace extracts showed antibacterial activity against *Listeria monocytogenes* and *Staphylococcus aureus*, while according to García-Lomillo et al. [45], extracts of

the seedless part of the pomace show antibacterial activity against total aerobic mesophilic bacteria, lactic acid bacteria and *Enterobacteriaceae*. According to Silvan et al. [102], grape seed extract shows antibacterial activity against *Campylobacter* spp., with phenolic acids and catechins being responsible for the inhibitory effect of the extract. Grape pomace extracts are also used in cosmetics.

According to research conducted by Wittenauer et al. [103], the effectiveness of grape pomace as an inhibitor of the activity of proteolytic enzymes such as collagenase and elastase, related to skin aging has been tested. The best results of enzyme inhibition have been obtained with hydrophilic polyphenols such as phenolic acids, especially gallic acid.

There are commercialized cosmetic products with grape polyphenols, such as day and night creams "Pure Super Grape" (Marks and Spencer - United Kingdom), anti-wrinkle cream and protective cream "Caudali" (France) with the belief that they use polyphenols from grape seeds [27].

3.2.2. Utilization and application of dietary fibers from by-products of the wine industry

Dietary fibers are defined as "carbohydrate polymers with ten or more monomer units, which are not hydrolyzed by endogenous enzymes in the human small intestine" [120]. The main effect associated with the consumption of dietary fiber is to reduce the risk of cardiovascular disease, diabetes, to improve transport through the digestive tract, to reduce cholesterol and obesity, and protection against cancer [27].

The monosaccharide composition of grapes is diverse and consists mainly of rhamnose, arabinose, xylose, mannose, galactose, glucose, uronic acids (mainly galacturonic acid) [41,121]. Grape skin contains a large amount of homogalacturonan and small amounts of pectin polysaccharides (ramnogalacturonan I and ramnogalacturonan II) [121]. Pectins with a low degree of methyl esterification are the main polymer components of the grape pomace cell wall, while cellulose is the dominant polysaccharide of the stem cell wall [121]. According to Kim et al. [122], grape seeds do not only contain oil and phenolic components, but also contain about 40% of fiber. Pectin is a highly valuable ingredient in functional food widely used for its gelling ability and as a stabilizing agent [27].

Dietary fiber extraction can be performed in several ways: conventional solvent extraction, microwave and ultrasonic extraction, or enzymatic extraction method [123]. For the extraction of sugar and polysaccharides (soluble fibers) from dried grounded pomace (different particle sizes), grapes of the *Pinot Noir* variety, according to Beres et al. [41], hot water (different temperatures) was used, with the application of different substance:solvent ratio. According to Minjares-Fuentes et al. [124], ultrasonic extraction has been used for extraction of pectin from pomace with citric acid as an extraction agent, the obtained results suggesting that this type of extraction may be a good option for

industrial application. Recently, enzyme extraction has attracted much attention due to the need for ecological extraction methods, however, the application of enzyme treatment or pretreatment can affect the cell wall structure of grape pomace, breaking the glycosidic bonds of polysaccharide chains to mono- and oligosaccharides [36].

Dietary fiber of grape pomace has the potential to be used in various food products such as bakery products, beverages, meat products, and can be used in cosmetics and the pharmaceutical industry as well [27,125]. Numerous studies have been conducted with the aim of using pomace and its fractions in various food products such as bread [105,108], biscuits [108], muffins [113] or even yoghurt [118], enriching them with valuable fibers (Tab. 1).

Grape pomace skin is a good source of lignin, cellulose and hemicellulose, so it has great potential as an environmentally friendly material [123]. The extremely high content of soluble sugars in white grape pomace can be used to form innovative biodegradable packaging materials with excellent flexible properties [125].

3.2.3. Obtaining tartaric acid from by-products of the wine industry

One of the alternatives for valorization of oenological waste, pomace and sediment is through the production and utilization of tartaric acid [31,126-130]. Tartaric acid is a significant product obtained from wine pomace that has found application in various sectors dealing with food, due to its antioxidant, preservative properties, i.e. pH regulatory properties [83].

Flow diagram of the technology of obtaining tartaric acid from wine lees, recommended by Rivas et al. [129], is shown in Fig. 9.

Utilization of tartaric acid from wine lees and grape pomace involves extraction with dilute acid or warm water [127], precipitation of tartrate with calcium salts [128] and finally conversion of calcium tartrate to tartaric acid with sulfuric acid [28]. According to Versari et al. [128], analysing the recovery of tartaric acid from three different wine wastes, at three different pH values of the medium (5.2; 6.5; 9.0) with the addition of different amounts of calcium chloride (7.6; 11.4; 15.2 g/dm³), it was concluded that the utilization of tartaric acid is maximal at low pH (5.2) and with the addition of larger amounts of calcium chloride (15.2 g/dm³). According to research [127], it was concluded that extraction with warm water gives a higher utilization of tartaric acid per kg of grape pomace. More recently, a study conducted by Kontogiannopoulos et al. [126], clearly showed that the utilization of

tartaric acid from wine lees can be achieved by using a cationic ion-exchange resin under mild conditions (ambient temperature), thus achieving the utilization of tartaric acid of 75% and also avoiding the formation of calcium sulfate sediment from the conventional process. According to Braga et al. [131], between 50-75 g of tartaric acid can be obtained from one kilogram of wine pomace or between 100-150 g of tartaric acid from one kilogram of wine lees.

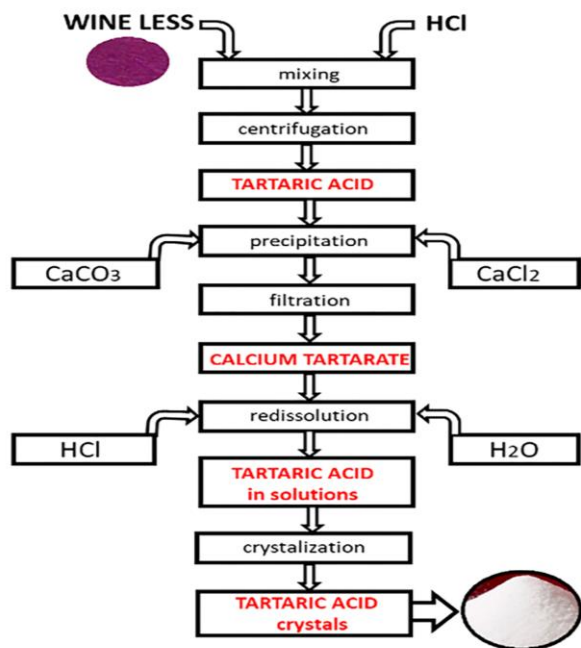


Figure 9. Flow technology diagram of production of tartaric acid from a wine precipitate/less (adapted from [129])

Slika 9. Dijagram toka tehnologije dobijanja vinske kiseline iz vinskog taloga (prilagođeno iz [129])

3.2.4. Utilization and application of grape seed oil

Grape seeds are roughly composed of about 40% fiber, 10-20% lipids, 10% protein, as well as other constituents, such as complex polyphenols, sugars, minerals, etc. [132]. Grape seed oil is widely recognized as a source of unsaturated fatty acids and polyphenolic components [77], and even after the extraction of oil from seeds there remains unused polyphenolic compounds [133], mostly in seeds - about 70%, 20% in the skin and about 10% in pulps [43].

Since the production of oil by the classical mechanical pressing process does not give a high yield, as well as the extraction with solvents such as hexane is doubtful due to its potential environmental toxicity [134], as well as residue

issues, new extraction procedures are subject of research. Some of the promising extraction techniques suitable for oils are supercritical fluid extraction (SFE) [135-137], as well as ultrasound-assisted extraction (UAE) [138].

The bioactive components of the oil, such as phytosterols, tocopherols, tocotrienols, flavonoids, phenolic acids and carotenoids, enable the widespread use of oils in both the pharmaceutical and food industries, especially given the trend of replacing animal ingredients with plants [27].

Taking into account the growing market demand for functional foods, one of the interesting applications is the replacement of some fats and saturated fatty acids of meat with unsaturated fatty acids from grape seed oil, which reduces caloric value, lowers cholesterol and improves certain sensory properties [139]. Grape seed oil has the potential as a raw material for biodiesel production. When obtaining biodiesel from vegetable oils, an important parameter is the composition of fatty acids, where monounsaturated fatty acids are preferred over polyunsaturated [27]. Conversely, oils with polyunsaturated fatty acids are more valuable in the pharmaceutical industry due to their antioxidant properties. Grape seed oil can also be used here due to bioactive components such as phytosterols and squalene, which coincides with the growing market demand for natural products without the addition of synthetic additives [140].

3.3. Application of biological treatments for obtaining high-value products from grape pomace

When it is talked about the application of biological treatments for obtaining products from grape pomace, it is mainly ment fermentation. Grape pomace is traditionally used in many European countries as a raw material for obtaining strong alcoholic beverages (spirits), which is justified due to the large amounts of residual sugar, both in soluble and insoluble forms. According to Corbin et al. [141], 31-54% w/w of grape pomace, calculated on the dry mass, consists of carbohydrates, of which 47-80% are soluble in aqueous media, while residues that are not soluble in ethanol mainly consist of polyphenols, pectin polysaccharides, heteroxylanes and cellulose. Problems that can occur with producers who use grape pomace as a raw material for spirits are unwanted microbiological processes that mainly occur due to inadequate storage conditions of the pomace, which affects on the undesirable properties of the quality of spirits [142]. All this can be solved by appropriate storage of the pomace until processing and by modeling of fermentation and distillation [143,144].

3.3.1. Bioethanol and biogas

Due to its high cellulose content, grape pomace is an excellent raw material for obtaining bioethanol and biogas, and at the same time the issue of waste from the wine industry is solved, which is very important from an ecological point of view. Also, there are no ethical disagreements in the use of industrial waste, as there is in the use of conventional crops, where primary purpose is human and animal nutrition [145].

Studies have shown that the pomace of white grape varieties [33], as well as white and black varieties [141] can serve as an excellent material for bioethanol production.

In addition to obtaining bioethanol, grape pomace can also be used as a raw material for obtaining biogas through the process of anaerobic digestion. The pomace contains larger amounts of lignin, that cannot be decomposed under anaerobic conditions, which is a limitation of this raw material [146]. Potential improvements in this process are constant stirring in the reactor [147] or previous extraction of polyphenols from the pomace [35].

An interesting study [148] dealt with the use of grape pomace to obtain biogas, which is then used to generate electricity. Namely, during the intensive processing of wine, which lasts about three months, the energy needs of the winery are great, most of which goes to cooling during must fermentation, which must not be avoided because low temperatures keep the key components of must. The dynamic model of a biogas-powered microturbine shows that the waste generated by the winery itself can be immediately converted into electricity and used on site, which is a practical and vivid example of circular economy in action.

This approach has potential even at the micro level, ie. both small and medium-sized enterprises could use the energy thus obtained, according to Fabbri et al. [149]. Successful experiments ElAchar et al. [150] and Eleutheria et al. [151] showed that Scale-up of such systems is also possible, which generally leads to the conclusion that grape pomace, alone or with other by-products (e.g. sediment or wine lees) must not be wasted, but can be used efficiently in different ways.

3.3.2. Additional fermentation processes of grape pomace

Due to the presence of lignocellulosic polysaccharides, grape pomace can represent a source for the production of glucose, xylose and other monomeric sugars by acid hydrolysis. Glucose in grape pomace can be used as a substrate for the production of lactic acid through

homolactic fermentation using the bacterium *Lactobacillus pentosus* [44], and also for the production of biosurfactants, which show good hydrophobic and emulsifying properties [152,153].

Campanella et al. [154] showed that probiotic cultures of lactic acid bacteria and bifidobacteria grow well on grape pomace substrates enriched with 1% glucose. In vitro studies of antioxidant activity, as well as simulation of gastrointestinal conditions, have shown that pomace is a suitable carrier for strains of probiotic bacteria, which represents another possible application of pomace.

Grape pomace can be an excellent substrate for the production of enzymes by solid-state fermentation. *Aspergillus awamori* has been used to produce hydrolytic enzymes [155], xylanases and pectinases [156]. These enzymes can further be used to clarify juices [157], which represents a direct revaluation of by-products and a reduction in their amount in industrial plants.

3.4. Agricultural and ecological application of grape pomace

Wine waste can potentially be used for soil conditioning and as a fertilizer [48]. During composting, organic matter undergoes microbiological processes in mesophilic and then in thermophilic conditions. The transition to thermophilic conditions may be an obstacle to the use of grape pomace due to the low pH value that can inhibit this transition [28]. The solution of this problem took the direction of the joint composting of pomace with other raw materials. The mixture of hydrolyzed grape pomace and wine lees showed good initial characteristics during composting of lignocellulosic waste, although the final results were similar for this mixture and raw grape pomace [158]. The use of compost from wine waste increases the percentage of organic matter, nutrient levels, microbiological biomass and improves the physical properties of the soil such as aeration and water retention capacity [48]. According to Arvanitoyannis et al. [48], the application of compost from agricultural waste in the soil can lead to problems related to the content of heavy metals.

One study [159] suggests that biochar obtained from grape pomace, as well as from other agricultural residues, can be used as a source of phosphorus in the soil, ie. that it can improve plant growth, taking into account that chemical composition of soil and other conditions also play a very important role. In addition to phosphorus, biochar produced by pyrolysis from grape pomace also contains N, K, Ca, as well as significant amounts of Na, Mg, Fe, Zn and other nutrients [160].

Wine waste can be a potential adsorbent for heavy metals [48,161], thanks to carboxylin, amino and hydroxyl groups from proteins or phenols that can bind metal ions.

4. CONCLUSION

Taking into account the predictions of population growth on Earth, the food industry is expected to increase production enormously, which inevitably brings with it an increase in the amount of waste generated. Unlike some other industries, this is a potential raw material that contains invaluable amounts of bioactive substances, which would be a shame not to use. The aim of this paper was to show that waste from the food industry is not waste in the true sense of the word, but a raw material that can be included in other processes, thus satisfying the basic principles of circular economy - regeneration and circulation.

Organic components of waste of plant origin are interesting for further utilization, because they contain large amounts of highly valuable molecules. The wine industry, as the main industry when it comes to grapes as a raw material, generates large amounts of this kind of waste. In this review of the literature, various innovative solutions are given that show what to do next with the by-products of wine production, primarily grape pomace. In addition to the classic and well-known use in the spirits industry, through composting or as an addition to livestock food, new solutions are presented - pomace as a significant bioenergy source, utilization of the most important substances from pomace, such as polyphenolic compounds, dietary fiber, tartaric acid, oils, then a review of pomace as a raw material for obtaining biofuels, enzymes, biosurfactants, etc.

Since the possibilities of usage in only one branch of the food industry are so diverse, which is confirmed by the mentioned references, it remains only to suggest that examples of good practice, such as circular economy, should not be forgotten or theorized, but become a reality through legal regulations.

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IZVOD

CIRKULARNA EKONOMIJA U PREHRAMBENOJ INDUSTRIJI

Koncept cirkularne ekonomije prevazilazi zastareli koncept linearne ekonomije, koji podrazumeva nekontrolisanu eksploataciju prirodnih resursa i protok materijala od fabrike preko korisnika do deponije. U cirkularnoj ekonomiji dolazi do zatvaranja kruga: proizvod – otpad – proizvod. Od industrije se očekuje da funkcioniše kao prirodni eko-sistem i da otpad iz jedne industrije postaje sirovina u drugoj tj. da podražava kruženje, odakle potiče naziv cirkularna. Generalno, cirkularna ekonomija je opšti pojam koji obuhvata sve aktivnosti koje smanjuju, ponovo koriste i recikliraju materijale u procesima proizvodnje, distribucije i potrošnje. Uzimajući u obzir predviđanja o rastu populacije na Zemlji, od industrije hrane se očekuje porast proizvodnje, koji neminovno sa sobom nosi i povećanje količine generisanog otpada. Organske komponente otpada biljnog porekla interesantne su za dalje iskorišćenje, jer sadrže velike količine visoko vrednih molekula. Cilj rada bio je da se pokaže kako otpad iz prehrambene industrije nije otpad već sirovina koja se može uključiti u druge procese, osnovni principi cirkularne ekonomije – regenerativnost i kruženje. Vinska industrija, kao glavna industrija kada se radi o grožđu kao sirovini, stvara velike količine ovakvog otpada. U ovom pregledu literature data su razna inovativna rešenja koja pokazuju šta dalje raditi sa nus-proizvodima dobijanja vina, pre svega komine grožđa. Osim iskorišćenja u industriji jakih pića, putem kompostiranja ili kao dodatka stočnoj hrani, prikazana su nova rešenja – komina kao značajan bioenergetski izvor, iskorišćenje najvažnijih supstanci iz komine, kao što su polifenolna jedinjenja, dijetetska vlakna, vinska kiselina, ulja, zatim osvrt na kominu kao sirovinu za dobijanje biogoriva, enzima, biosurfaktanata, itd.

Ključne reči: cirkularna ekonomija, prehrambena industrija, vinska industrija, komina.

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