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Article

By-Products of Wine Production in the Service of the Circular Economy

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Abstract: The purpose of this preview paper is to bring closer the points of view regarding the connection between by-products of winemaking and the circular economy as a guarantor of revaluation of wine waste. As a very important agricultural activity, wine production generates large amounts of solid organic waste in addition to wastewater, the disposal of which represents a huge ecological challenge as well financial cost for the producers. The by-products that fall behind in such production are pomace (stalks, skins, seeds), wine lees and some parts of the vine. The potential of using stated above as a source of possible biologically active substances can be used in various industries to obtain products for the benefit of life as known to humanity, including other species. This improves the quality of human existence, and Mother Earth becomes less polluted. We should not forget fact that we borrowed the Earth we live on from our descendants and did not inherited it from our ancestors. The Republic of Serbia is also a part of this loop with its participation in wine production and all of the above.

Keywords: winemaking by-products; circular economy; Republic of Serbia.

1. Introduction

One of the fundamental pillars on which human society rests is the protection of the environment and nature. The sustainability of the circular economy, as argued by Blewitt (2017), is that by-products are not necessarily waste, already can close the recoverability circle to become resources [1]. At the same time, it is very interesting to observe the intertwining of profit and ecosystem protection as the principle on which the circular model is based. When food is thrown away, all the resources used in its production are lost, creating economic losses and negative effects on the environment. In the world, about a third of the produced food is thrown away every year, which amounts to about 931 million tons [2].

Environmental problems that may arise are related to the non-use of by-products of fruit production and processing, especially when by-products are discarded in the fields or burned causing damage to the ecosystem [3]. Agricultural production is associated with soil erosion, groundwater pollution, and drastic reduction of biodiversity and it is also recognized as a sector that significantly contributes to greenhouse gas emissions [4]. The positive impact of reducing waste and losses in the production chain is reflected in the cost of production (land, water, energy, storage, transportation), increasing the efficiency (usefulness) of food systems, raising food and nutrition safety to a higher level (health effect, nutritional value) and contribution to healthier environmental sustainability (ecological performance, circular economy) [5].

One of the Sustainable Development Goals outlined by United Nations' in 2015 intends to 'halve the per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, by 2030. Sustainable development in accordance with some of the 17

global development goals and 169 associated goals adopted by the UN is manifested in the transformation from a linear to a circular bioeconomy [6].

The Republic of Serbia is also participating in the path of this transformation with the adoption of the Industrial Policy Strategy for the period from 2021 to 2030 [7], which recognizes aapproaching the agro-food industry with a circular and non-linear mindset leads to reduced resource waste and greater economic savings. Implementing circular economy strategies can improve the environmental and economic sustainability of the wine production process.

In this context, waste valorization and a closed-loop supply chain are key elements of industrial symbiosis [8].

2. Grape and wine production in the Republic of Serbia

Grapes are the most widespread fruit species in the world. Although many grape-based food products can be found in the market, the fact is that almost 80% of grapes are used for wine production, about 13% are consumed fresh, and the remaining 7% are processed into fruit juices or raisins [3]. According to data from the International Organization of Vine and Wine (OIV) for 2023, grapes were grown on 7.2 million hectares in the world, and over 237 million hectoliters of wine were produced [9]. Global grape production in 2022. reached 74.94 million tons [10].

Within wine-growing Serbia, there are three regions with 22 district county and 77 vineyards [11] with a clearly defined vision of viticulture and winemaking that reads: "Unique in diversity, development and knowledge". The Republic of Serbia has a moderate-continental climate and very favorable climatic conditions for agricultural activity. Although the area between the 42nd and 46th degrees of north latitude guarantees a favorable zone for growing vines, and thus wine production, the decline in wine production in the Republic of Serbia dates back to almost two decades ago [12], whose trajectory still continues [13]. Despite this, the Republic of Serbia produces sufficient quantities of grapes and wine, and thus by-products that are part of the circular economy and wine production loop.

The Law on Wine [14] prescribes the obligation to maintain the Winegrower's Register and the Winery Register, and there is a defined base of data sources necessary for an adequate overview of the sector. Every country takes care of having knowledge about the real situation in agriculture, with the aim of creating a sustainable agricultural policy, as is done by the Republic of Serbia. That's why in the Republic of Serbia, in 2012, a comprehensive inventory of agriculture was made, including vine plantings, and the data goes back to 2023. (Table 1).

Table 1. Area under vineyards, grape yield and production of grapes and wine; 2012-2023 [15-17].

Year	2012.	2013.	2014.	2015.	2016.	2017.	2018.	2019.	2020.	2021.	2022.	2023.
Grapes												
Productive area, ha	22.150 38.398	22.150 22.791	21.200 22.791	21.201 22.150	21.201 22.150	21.201 22.150	20.333 21.328	20.501 21.328	19.840 20.466	20.113	19.973 20.113	18.349 20.113
Production, thous. t	128 263.4	164 199.9	122.4	170.6	145.8	165.5	149.5	163.5	160.3	155.7	162.4	131.5
Yield per ha, t	6	7.7	5.8	8.0	6.9	7.8	7.4	8	8	7.7	8.1	7.2
[4]**Wine, 000 hl**	1581	1200	198 734	241 758	362 648	375 736	331 711	279 617	240 558	251 544	233 544	215 544

Data sources from Table 1 were taken from Report on the state of agriculture in the Republic of Serbia, prepared by the Ministry of Agriculture, Forestry and Water Management for the period from 2012 to 2023, as well as from the OIV. In the rest of the text, we will refer to the data collected from the Ministry of Agriculture, Forestry and Water Management. The year 2012 was taken as the starting

year, because in that year the Census of Agriculture was conducted, which was comprehensive and largest up to that time. If we are going to look back 20 years, then we should state that in 2005, the production of grapes in the Republic of Serbia was 240 643 tons [19] and if this that data is compared with the data from Table 1 for the year 2023, the comparison of those two years shows a drastic decreasing trend (45.3%) in grape production.

Observed in the period on which Table 1 is based, it can be seen that the trends were oscillating, when we talk about grape production, with a sharp decrease in the last year of observation, and falling when it comes to wine production, especially in the last 5 years. Average wine production in the period (2019-2023) was 24.36 million liters.

The area under vine plantations was around 20.000 hectares for a long time, but in the last year of the census, it experienced a sharp decline. Depending on the climatic conditions in the observed years from Table 1, the realized yields varied, and based on the arithmetic mean were 7.38 tons per hectare. The average production of grapes in the five-year interval (2019-23) according to Table 1 was 154.709,6 tons of grapes. In Table 1, the data presented for vine plantations and wine production differ from two different data sources, except for grape production where they are identic for period 2014-2022. The difference is based on the different methodology of data collection, which is partly explained in footer of Table 1.

3. Waste in viticulture and winemaking

During wine production, 1.3-1.5 kg of by-products are produced per liter of wine produced, of which about 75% goes to waste water [20].

Taking into account the data provided by the Ministry of Agriculture, Forestry and Water Management and observing the average wine production in the last 5 years (Table 1), the Republic of Serbia produces by-products of the wine industry in the amount from 31.668 to 36.540 tons. During the processing of grapes into wine, solid organic waste and wastewater are created, which have a harmful effect on the environment. Winemaking by-products are pomace (skins, seeds, and stalks) and lees, which make up about 20-30% of the total amount of processed grapes [20].

Each year, around 20 million tons of wine by-products are produced, corresponding to 30% of the total quantity of vinified grapes [21].

Grape pomace

Grape pomace is the most produced organic waste in wineries, representing around 62% of the total waste [22]. It consists of 25% stalks, 25% seeds and 50% skin [23], and is formed during the wine production process, after the fermentation step in the case of black grapes, and before it in the case of white grapes [24]. It is a rich source of water-soluble pigments (anthocyanins), which are often used to color various food products, such as soft drinks, wines, liqueurs, desserts, ice creams and jams [9].

Grape stalks

Grape stalks are the vertical part of the bunch that is removed before the vinification process. They represent 3–5% of the raw matter of the processed grape [25]. Green and sustainable subcritical water extraction techniques allow for the extraction of active compounds from grape stalks, adding value to this agricultural waste. These extracts can be used to develop active food packaging materials [26] and as a raw material for the microbial synthesis of polymer precursors [27]. The commercial value of the petioles is currently low and they are mainly used as animal feed or as additives in soil nutrients. However, due to the high content of lignin, cellulose and tannin, the stalks have the potential for bioconversion into high-value products. Thus, they can be used in the production of adhesives and resins for use in wood technology [28].

Grape skins

The grapes skin makes up the largest part of the composition of grapes and is mainly used as animal feed. Grape skin extracts are mainly used as color enhancers derived from anthocyanin, and

due to the high content of cellulose, it can be used in the production of ecological paper and in the food and pharmaceutical industry as a natural thickener [29].

Grape seeds

Grape seeds are generally used to produce oil and meal for human and animal consumption. They represent about 5% of the grape weight. Grape seed oil has found its most significant application in the cosmetic industry [30], as an ingredient in products for moisturizing the skin, softening the texture, tightening the skin, reducing swelling, and in other products with a hypoallergenic effect. Also, recently is used in the food industry as an alternative culinary oil, often as a dressing or sauce or part of a salad dressing [31].

Wine lees

Wine lees make up 2-6% of the total amount of by-products in wine production, and it is formed as a residue at the bottom of wine vessels during a series of operations in the technological process of wine production [32]. Since wine lees is considered a significant pollutant of the soil, its disposal represents an exceptional cost for wineries, focus is on optimal use and valorization. Wine lees, with appropriate processing, can be a useful source of numerous high-value bioactive ingredients that have potential applications in the wine, food, biotechnological, cosmetic and pharmaceutical industries. Sometimes only extraction with ethanol and tartaric acid is carried out, as an alternative to direct disposal of the lees, which otherwise represents a high cost for wine producers [33].

Wastewater

The wastewater generated from wine lees and grape marc is referred to as vinasses, and is characterized by a high content of solids composed mainly of dead yeast, grape pulp, skin and seeds [34].

Vine parts

Pruning wood is the main by-product from vine activity, which can be used to improve the organic matter directly in the vineyard or by compost process, or it can be transformed into wood pellets for heating or electric energy production [35].

4. Valorization of by-products

In order to realize the circular economy in the best possible way, it is necessary to connect the raw material base and industry based on the principle of recirculation and the use of waste as a secondary raw material [36]. Certain products that are created at this production level can be recirculated into the first production circle (recirculation), and some of the waste or secondary products can be returned to agricultural production. In the biotechnological processing of secondary products and wastes of the food industry, wastes and secondary products can also be created that can be used as tertiary raw materials in new, alternative technologies, from which, depending on the type of initial secondary raw material, different products of wide use or energy sources can be produced [37].

Large quantities of by-products are created in the production of wine, which makes it difficult to manage the waste mass of grapes with potential negative impacts on the environment due to the organic matter, acidic pH, salinity and heavy metal content and causing economic and environmental issues [38]. Some of the waste produced has nutritional and functional potential, as well as biological properties, and have been classified as by-products [39]. Grapes contains compounds such as polyphenols, carbohydrates, organic acids, dyes, etc. The essence is that the by-products of grape processing and wine production can be used for the valorization of functional ingredients or bioactive phytochemicals that can be devoted to the production of pharmaceutical, food and cosmetic ingredients [40].

Some already existing, along with a lot of newer techniques and technologies for the valorization of the by-products of the wine industry, are shown as follows:

- producing functional food to enhance the nutritional value of products like bread, cereals, pasta aromatized waters, dairy products, alcohol, sugary beverages, and processed foods [21,26].
- extracting bioactive molecules, especially phenolic compounds, as the primary applications of nanomaterials in pharmaceuticals and cosmetics [21,41].
- biogas production by anaerobic fermentation with reduction of greenhouse gases [27].
- recovering of tartaric acid which can be further transformed into succinic acid to produce biopolyesters [27].
- usability of by-products as a feedstuffs due to their richness in nutritional and bioactive compounds, such as dietary fiber and polyphenols [42,43].
- hydrothermal carbonization for the purpose of obtaining bioenergy [44].
- novel methods of extraction and new nanotechnological applications [45].
- using of new new technologies in the conversion of biomass into renewable fuels [46].
- anaerobic digestion that produces biogas, biomethane and carbon dioxide [46].
- pyrolysis for conversion into bio-oil (main product), biochar and gas (synthetic) in an oxygen-free environment [46].
- extracting by high-voltage electrical discharge and ultrasound-assisted extraction [47].
- producing alcoholic beverages post-distillation from white wine pomace to make grappa [26], which is also known as komovica [48].
- thermal gasification to obtain synthesis gas (production of methanol or ammonia and motor fuels) [49].

The valorization of mentioned by-products leads to obtaining very valuable products both from a nutritional and industrial point of view and its valorization demonstrates an important economic efficiency.

5. Conclusions

It is known that wine production annually generates around of 20 millions of tons of waste on a global scale. Due to the impact on the environment, the resulting waste must be disposed of properly. Since the adequate disposal of waste obtained from the production of wine simultaneously increases production costs, there is no place to wait, but the waste should be valorized, thus reaching an ecologically and economically acceptable solution.

The Republic of Serbia, yearly, participates in the production of this waste with about thirty to forty thousand tons. In the wine industry after the processing of grapes, a series of by-products, such as pomace (stems, skins and seeds) and wine lees, can be turned into very valuable products from both a food and industrial point of view. Until recent days, some of the technologies have already been implemented on an industrial scale, while others are in the development phase for potential application, both for human and other species.

A circular loop is realized when the raw material base and industry are connected on the principle of recirculation and the use of waste as a secondary raw material, as shown in the paper.

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