

Sustainability of Wine Production

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Abstract: Wine production is one of the most important agricultural activities around the world. The production of wine involves the use of a large number of valuable resources, such as water, fertilizers, and other organic products. Moreover, it produces a large amount of wastewater and organic waste that must be treated adequately to avoid contaminating the areas of production. The nature of the waste produced depends very closely on the specific vinification procedures, which also affect the physical–chemical properties of the residual material generated, whose characteristics determine its subsequent use and even condition the subsequent specific recovery circuit in which can be integrated.

Keywords: wine; waste; residues; recovery; sustainability

1. Introduction

One of the main environmental problems in producing countries is the increased amount of lignocellulosic products generated by the development of agro-industrial activity over the last 100 years. With the purpose to contribute to a healthy environment, the wastes through mechanical, chemical or biological processes are used as raw material for new products and applications. It is the so-called circular economy aiming at “zero waste” society [1].

The wine industry is one of the most powerful in different regions of the world. The amount of land dedicated to the cultivation of the vineyards turns this into one of the main agricultural activities of the human being. This large amount of production is associated with the use of a large number of resources, both in terms of water consumption and the use of organic and inorganic products (fertilizers). Sustainable wine production should be associated with the correct use of these elements both in the fields and in the cellars. Vine cultivation itself and basically wine making in cellars produces high amounts of waste and side-off products, including pomace, seeds, stems, prunings, yeast and bacteria lees, organic acids (tartrate), CO₂ and water. Unfortunately, only a few quantity of these materials are used for fertilization, animal feed, or generation of other products. Moreover, the by-products of wine can be used for valorization of functional ingredients or bioactive phytochemicals, that can be devoted to the generation of pharmaceutical, food, and cosmetic ingredients [2,3].

The definition of sustainability is a little complicated due to the special environmental issues of different wine-growing regions. Sustainability can be understood as the process of reduction of residues and its subsequent treatment in the elaboration of the wine. This implies, within the production chain, an adequate management of resources in terms of water and energy efficiency, both in vineyards and wineries. Sustainability will grow in importance in the minds of people, since climate change is a reality in the 21st century. The traditional winemaking processes are carried out through practices with hundreds of years of tradition. The resources used, both in terms of people and equipment, have not changed much in that time. Therefore, the application of new technological resources designed to reduce the amount of waste generated during the process is by no means

an easy task. It is necessary for the scientific community to develop practices for the recovery and transformation of by-products with a certain degree of innovation. On the other hand, markets demand new end products, and today's societies require that these be produced in an environmentally friendly way. All this must be done within an increasingly demanding legal framework. Processes must be efficient as well as legal [1].

For example, we could cite FAO data according to which the most common commodities in Spain are barley beer, wine, and olive and soybean oils (<http://faostat.fao.org>). The production of these foods is not exempt from the generation of huge quantities of by-products (millions of tons each year). If we do not want the environment to suffer serious irreversible effects, we must carry out appropriate management that eliminates them or leads to others. Among the by-products generated in greater quantity in the wineries, we highlight the grape pomace and stems (GPS). These by-products are not toxic in themselves, but their high organic matter content, together with the fact that they are produced in a high seasonal manner, make them a serious environmental problem [4]. GPS has a high content of tannins, or to put it another way, a very rich source of antioxidants, as well as high amounts of hemicellulose formed mainly by xyloglucans. The use of grape stems has been proposed as a biosorbent material for the elimination of toxic compounds, such as composting and also to obtain high added value compounds such as phenolic compounds with antioxidant activity [5]. Wineries are one of the most important agro-industrial activities in Southern Europe countries [6]. As it is well known, these industries generate high quantities of residues, also being a great loss of valuable materials. Some efforts have been done to reuse of by-products into other production chains. From the economic and environmental point of view, essential management problems can be approached. At a first stage, it is a worth issue to identify, quantify and characterize the wastes. In a second step the evaluation of residue sources and high-added value ingredients is done. Both the conventional and new microbial technologies applied for processing should be considered.

However, it is not easy to diminish waste production in wine production processes, as some of the practices are based in traditional processes, limited by physical infrastructures or human resources [7]. As a consequence, it is important to develop valorization procedures, leading to the implementation of waste management in the wine industry. Thus, taking into account that markets increasingly demand new end products, along with the environmental implications of the environmental risks associated with the activity, legislators have been led to generate an appropriate legal framework. On the one hand, this must support improvements in the processes of both the recovery of by-products and the recycling of waste, and on the other, ensure the efficiency of production processes.

Wine production is one of the most important agricultural activities around the planet. The main production areas are in Europe (Italy, Spain, France, Germany and Portugal), America (USA, Argentina and Chile), as well as Australia, South Africa and China [8] (Table 1).

About 300 million hl were produced during the 2018 campaign, according to the International Organisation of Vine and Wine (<http://www.oiv.int>). As is well known, wine production is associated with the use of a large number of resources, such as water, organic additives or fertilizers. In addition, the process involves the generation of significant amounts of both organic waste (skins, branches, seeds) and wastewater. Depending on the different procedures used in the production of wine in each production area, the waste produced varies slightly. All these aspects condition the physical-chemical properties of the waste material, whose characteristics determine its subsequent use and the specific recovery circuit in which it could be integrated in order to minimise the ecological footprint. Having a sustainable wine industry, integrated into a sustainable economy, requires innovative solutions that propose and evaluate feasible solutions from a technological point of view [9].

Table 1. Worldwide production of wine (millions hl).

Country	Media 2013–2017	2017	2018	Variation 2018/2017 in %
Italy	48.3	42.5	54.8	28.9
France	43.5	36.4	49.1	34.8
Spain	38.9	32.5	44.4	36.7
USA	23.2	23.3	23.9	2.3
Argentina	13.0	11.8	14.5	22.8
Chile	11.0	9.5	12.9	35.9
Australia	12.6	13.7	12.9	−6.1
Germany	8.6	7.5	9.8	30.7
South Africa	11.0	10.8	9.5	−12.5
China	13.1	11.6	9.3	−20.2
Russian Federation	5.4	6.3	6.5	3.0
Portugal	6.4	6.7	6.1	−10.0
Romania	4.0	4.3	5.1	17.9
Hungary	2.8	3.2	3.6	14.6
Brazil	2.6	3.6	3.1	−13.2
New Zealand	2.8	2.9	3.0	5.8
Austria	2.2	2.5	23.8	10.8
Greece	2.7	2.6	2.2	−15.4
Moldavia	1.8	1.8	1.9	5.5
Switzerland	0.9	0.8	1.1	40.4
Bulgaria	1.3	1.1	1.0	−3.6
Other countries	14.8	14.5	15.0	3.4
Total	270.9	249.8	292.3	17.0

Source: International Organisation of Vine (OIV).

2. Characterization of Different Winery Residual Biomasses

2.1. Winery Industry

Winemaking generates different residues Figure 1 characterized by high contents of biodegradable compounds and suspended solids [10,11]. Although winemaking is considered as an environmentally friendly process, during the wine production process between 1.3 and 1.5 kg of waste is generated per litre of produced wine, 75% of which is wastewater [12]. The other major residues from wine-making activity are represented by: organic wastes (grape pomace, containing seeds, pulp and skins, grape stems, and grape leaves), wine lees, emission of greenhouse gases (CO₂, volatile organic compounds, etc.), and inorganic wastes (diatomaceous earth, bentonite clay, and perlite). A total of 14.5 million tons of grape by-products are produced annually in Europe alone [13].

Bustamante et al. [14] analyzed different residues from the wine industry and found that winery and distillery waste have a low pH (mean values ranged from 3.8 to 6.8) and electrical conductivity (1.62–6.15 Ds/m) and high organic matter content (669–920 g × kg/L). Moreover winery residues have high concentrations of macronutrients, especially K (11.9–72.8 g/kg), as well as high concentrations of polyphenols (1.2–19.0 g × kg/L) and low concentrations of micronutrients and heavy metals contents. The waste must be conditioned before use as these properties are incompatible with agricultural requirements [14].

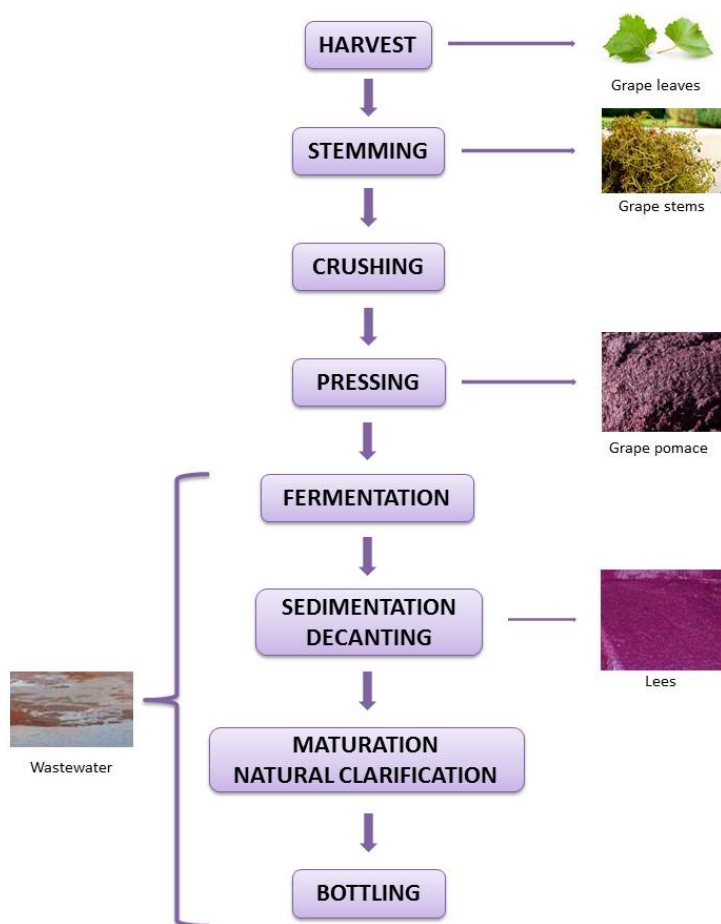


Figure 1. Diagram of the vinification process including the generated residues.

2.2. Grape Leaves

Leaves from *Vitis vinifera* L. constitute the less studied or valorized residue of the grape crops and the winery industry. The limited information available on its composition suggests that its content in organic acids, phenolic acids, flavonols, enzymes, vitamins, carotenoids, tannins, procyanidins, anthocyanins, lipids, terpenes, and reducing or non-reducing sugars is interesting [15]. The chemical composition of the leaves of the vine has led to interest in this plant material as an innovative source of products with interesting nutritional properties, enhancing its biological potential. Currently, vine leaves are part of the production processes of food ingredients, while their juice is recommended for eye washing, given its antiseptic action [16].

2.3. Grape Stems

Grape clusters or grape stems are another waste product produced in the winemaking process. The included procyanins are an interesting source of astringent compounds that can be used in other processes [17]. To avoid a negative effect on the organoleptic characteristics of wine, this substance is removed before the vinification process. The quantity of stems varies between 1.4% and 7.0% of the raw matter processed [18]. It can be said that the commercial value of the grape stalks is low. Their most frequent uses are the production of nutritious compounds for the soil as well as for fattening animals. Some authors point out that their composition is adequate to be also considered as a source of antioxidants or dietary fiber [19]. The average moisture percentage of grape stems has been reported as ranging from 55% to 80%, with the higher variability attributed to the grape variety. The content of

grape stems alcoholic insoluble residues is 71% of the dry matter and no differences between white and red varieties have been observed [20]. Concerning the phenolic composition, their content has been shown in flavan-3-ols, hydroxycinnamic acids, monomeric and oligomeric flavonols, and stilbenes [21]. In this regard, phenolics from grape stems have been shown to be approximately 5.8% on a dry weight basis [22].

2.4. Grape Pomace or Press Residues

The production of grape juice is associated with the generation of other types of waste, commonly called grape pomace. The differences in the proportion of grape pomace in relation to the total quantity of grapes used during the process is determined by the total material considered as well as the possible incorporation of grape stems as part of the waste when calculating the relative proportion [23].

As regards the general composition of the pomace, the humidity varies between 50% and 72% depending on the grape variety used and the degree of ripening. Insoluble residues have a lignin content of between 16.8% and 24.2% and a protein content of less than 4%. In the usual way, peptic substances are the majority polymer-type constituent of the cell walls present in grape pomace, varying from 37% to 54% of the cell wall polysaccharides. On the other hand, cellulose is the second type of polysaccharides found in grape pomace, varying between 27% and 37% [20].

If we analyse its composition, grape pomace is characterised by its suitability for use in different industrial processes, both in the extraction of grape seed oil and polyphenols (including anthocyanins, flavonols, flavanols, phenolic acids and resveratrol), in the production of citric acid, methanol, ethanol and xanthan by fermentation and in the generation of energy by methanisation. Taking into consideration its polyphenolic content, different authors conclude that this by-product is endowed with a high antioxidant activity, suggesting that grape pomace produced in wineries can be used in the pharmaceutical, cosmetic and food industries as an alternative source of natural antioxidants [2,24].

Another option is to consider grape pomace separately, using the seeds on the one hand and the skins on the other. The relative proportion of seeds ranges from 38% to 52% of dry matter according to some sources [25], while others attribute a much lower proportion to it, which could be around 15% of grape pomace [26]. Regarding the composition of grape seeds (*w/w*) fiber content is up to 40%, 16% essential oil, 11% protein, 7% complex phenolic compounds like tannins, and other substances like sugars and minerals [27].

The phenolic content of the grape seeds is also very interesting, as it ranges from 60% to 70% of the total extractable compounds. This high concentration is very attractive, based on the fact that in the process of pressing the grapes only a small proportion can be extracted [28], and this fact has attracted the interest of the industry to use it as a source of natural antioxidants [29].

Usually, grape skin represents 65% of the total raw material of grape pomace. Grape skin is a rich source of phenolic compounds, although the final yield depends on the specific vinification process and extraction method used. [30]. Therefore, grape skin is a rich source of phenolic compounds, even though the final yield is dependent on the specific vinification process and the extraction process used. Some factors as the type of solvent, temperature or time affect the process [31].

Moreover, grape pomace has interesting proportions linoleic acid (55–75%) [32]. Further studies are recommended since there is only general information on the fatty acid composition of grape pomace. Grapes are considered to contain high levels of polyphenols with as much as 70% retained in the pomace after the extraction of juice from grapes [33]. The main polyphenols in grape pomace are phenolic acids, flavan-3-ols, flavonols, anthocyanins, and proanthocyanidins. Total phenolic and flavonoid contents among cultivars range from 55.5 to 153.8 mg gallic acid equivalent (GAE)/g and 38.9 to 91.7 mg rutin equivalent/g, respectively. Total tannin, monomeric anthocyanin, and proanthocyanidin contents in grape pomace extracts range from 54 to 152.2 mg GAE/g, 0.02 to 11.2 mg cyanidin-3-glucoside equivalent/g, and 21 to 51.7%, respectively [33].

2.5. Wine Lees

Wine lees are the residues that appear at the bottom of the wine production tanks, after the fermentation process, while it is stored or after further treatment. This also includes the waste generated after filtering and centrifuging the product. The typical composition of the lees includes yeast, tartaric acid, phenolic compounds and other materials of an inorganic nature [34]. Lees are fundamental in winemaking as they interact with (poly)phenolic compounds, which are directly involved in colour and other collateral organoleptic properties, as well as adsorbing them [35]. Moreover, lees liberate enzymes favouring the hydrolysis and transformation of (poly)phenolic substrates in phenolics with high added-value and interest like gallic acid or ellagic acid [36]. The presence of anthocyanins (6–11.7 mg/g $\times$ dw (dry weight)) and other phenolics (29.8 mg/g $\times$ dw) in wine lees [34] has also been reported. It is particularly interesting to analyse the wine lees. Their high content of bioactive molecules that can be exploited to obtain extracts or semi-finished products of interest for use in the food, nutraceutical and pharmaceutical industries, means that they are currently being evaluated from different points of view [37].

2.6. Winery Wastewater

Today's society is particularly interested in managing both agricultural soils and the water resources that support them in a sustainable way. The use of waste water for irrigation of farms is being implemented throughout the whole of the country, and in order to be acceptable, it is necessary to pre-process it at different levels [38]. Agricultural holdings dedicated to wine production are within this context. In quantifiable terms, each tonne of grapes that is processed generates around 3000–4000 L of wastewater [39]. Winery wastewater (WWW) generate waste on a regular basis as a result of the numerous cleaning operations that are carried out in the wineries while the wine is being made. The effluents contain many polluting residues, both organic and inorganic. This is why they generate a high environmental impact. No less important is the large amount of waste produced as well as its production in a seasonal (discontinuous) manner. The final destination of the WWW is variable, depending on each winery, both in size and location. Sometimes WWW are directly disposed of in the public sewerage system. In other installations, far from the urban nucleus or of great size, the WWW are poured directly on the soil [40]. This activity raises many concerns, as WWW present different pollutants that can negatively affect irrigated soils, both in terms of their direct physical-chemical properties, as well as the growth of the agricultural crops affected and even the end consumers [41]. Likewise, there is great variability in the contents of the WWW, since it depends both on the type of operation carried out in a winery at a given time and on the possible treatment processes that are carried out. For all these reasons, the reuse of the WWW must be analysed in detail in each agricultural operation [42,43]. While wineries already have some effective treatments for processing WWW, the industry needs alternative treatment methods that will (i) maximize the efficiency and flexibility of the treatment process to meet existing legislation regulating the disposal of winery effluent, and (ii) reduce both the environmental footprint and overall investment/operating costs. Recently, interesting approaches have been described as a sustainable solution for the use of winery wastewater in xanthane bioproduction [44].

3. Conclusions

The wine industry is one of the agricultural activities that generates the greatest benefits to those areas where it is carried out. However, having this type of agricultural exploitation is not exempt from damage to the environment where it takes place, so the waste generated, usually considered as undesirable, is the price to pay. If we first evaluate the type of waste generated in a winery, it does not seem to be interesting from an economic point of view. Moreover, they do not usually generate added value, so the first option is usually to get rid of them in the most effective and economically viable way. With these premises, the efforts of the scientific community should focus on changing this

negative perception, and look at the waste products of wine production as an interesting by-product from an economic point of view, which can be eliminated, but is also profitable and a part of the overall business of wine production.

The technological advances we have today allow us to obtain final products different from the traditional ones. The processes have their complexity, since it is necessary to add knowledge coming from different scientific disciplines, going through environmental sciences, engineering, (bio)chemistry, bio(technology), logistics, economy or legislation of the wine sector. The collaboration of different professionals trained in each of these areas should allow us to obtain new innovative/alternative integrated models of wine production. In this way, we could achieve a society with a more sustainable economy, also respecting the environment.

The by-products generated in a winery can be treated from two points of view, as far as their valorization is concerned. The first one refers to the possibility of extracting phytochemical compounds with added value, interesting to be used in the elaboration processes of food [45], cosmetics [33] or even pharmaceutical products [46]. The second focuses on bioconversion processes based on the use of the waste generated as a raw material for the cultivation of microorganisms, either as a single substrate or as an additional nutritional supplement. The valorisation of the by-products obtained in the wine production process can therefore be used to grow yeasts, moulds and bacteria by applying different technological solutions. However, the heterogeneity of the by-products obtained in the winemaking process (biomass from pruning, grape lees, pomace residues and finally waste water) makes their use laborious. Its composition is variable, depending on the area of production and the technology applied in the process. Furthermore, it must be taken into account that wine production is a seasonal agricultural practice. The solution to these two disadvantages does not have the same level of complexity. The first point already has a technological solution, although there are practical reasons of an economic nature that make us far from being able to apply it. The second aspect, the seasonality associated with wine production, is far more complex and requires further research. Climatic conditions are a limiting factor and are difficult to solve, although a certain time distribution of the process of using the waste could contribute to considering it as a value-added by-product. An analysis of flexible processes on a small scale applicable to the processing of waste, using it in a discontinuous way, would be particularly interesting.

The monographic number presented by Sustainability allows us to review different processes of utilization of waste generated in the wine production industry. This should have a positive effect from different aspects, both scientific and technological, as well as economic, environmental and social. All the actors involved in the winemaking process should be able to influence the economic and technological aspects to open a realistic perspective of the valuation of the by-products generated in the wineries.

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Abbreviations

The following abbreviations are used in this manuscript:

WWW	winery wastewaters
GPS	grape pomace and stalks
GAE	gallic acid equivalent

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