Chapter

Wine Production Wastes, Valorization, and Perspectives

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Abstract

The wine sector generates high quantities of residues that are still poorly exploited as feedstock. Normally, these wastes are directly discarded into the fields or burned, thus causing environmental problems. Wine production wastes, like vine pruning and grape pomace, are available at relatively low prices and are considered prime materials for biochemical conversion into added-value products. In this context, the reutilization of these wastes is very important not only for minimizing environmental impact but also for obtaining higher profitability. The main objective of the present chapter is to address what are the possible reutilizations and valorizations of these wastes.

Keywords: vine pruning, grape pomace, grape stems, lees, waste valorization

1. Introduction

Agro-food residues with high organic content represent environmental hazards, but at the same time are sources of added-value compounds like polyphenols, carbohydrates, proteins, *etc.* In the context of circular economy, and according to the concept of reduce, recycle, and reuse, the valorization of these types of residues has become a priority in the last decade. Strategies for the valorization of food residues include their use for energy production and reprocessing the wastes for the making of functional materials, new products, and extracts. In 2021, 77 Mt. of grapes will be produced worldwide [1]. Around 70% of the grapes are used for wine production. During the winemaking process are generated different wastes that represent around 30% of the total grapes used. These wastes include vine pruning, grape stems, grape pomace, and lees. The first generated waste in the process of winemaking is vine pruning, which is calculated to be around 5 t/ha. Grape stems are the wastes from destemming the grapes and represent between 2.5 and 7.5% of the total weight of the grapes. Grape pomace (mixture of skins, seeds, and parts of stems) results from pressing the grapes and can represent between 25 and 45% of the total weight of grapes. Lees are the residual mass at the end of the fermentation process that sediments on the bottom of the fermentation vessel. It's a mix of dead yeast, grape skins, seeds, and stems and accounts for between 3.5 and 8.5% of the total generated waste [2].

Normally, a big part of the wine waste is incinerated, a process that has high operation costs and generates hazardous gases and ashes. It can be used also for animal feed or left in fields. Wine residues are not hazardous by nature, but the fact that wine production is concentrated in a specific period of the year poses potential pollution issues and implications.

There are different studies aiming at possible solutions for valorization and further reutilization of these wastes, according to the concepts of circular economy. The main intuition of the present chapter is the systematization and recognition of the existing research carried out on wine residue valorization.

2. The winemaking

The International Organization of Vine and Wine (OIV), which represents 49 member states, accounting for about 87% of world wine production, defines wine as the beverage resulting exclusively from the partial or complete alcoholic fermentation of fresh grapes (*i.e.* the ripe fruit of the vine), whether crushed or not, or of grape must, the liquid product obtained from fresh grapes, whether spontaneously or by physical processes such as crushing, removing stems from grape berries or crushed grapes, draining and/or pressing [3]. The European Union Law [4] defines wine in a similar way but is rather more restrictive. Wine means the product obtained exclusively from the total or partial alcoholic fermentation of fresh grapes, whether or not crushed, or of grape must. Fresh grapes are fruits of the vine used in winemaking, ripe or even slightly raised, which may be crushed or pressed by normal wine-cellar means and which may spontaneously commence the alcoholic fermentation. Only wine grape varieties belonging to the species Vitis vinifera or coming from a cross between the species Vitis vinifera and other species of the genus *Vitis* are allowable, except Noah, Othello, Isabelle, Jacquez, Clinton, and Herbemont. But, on the other hand, the Encyclopedia of Microbiology refers to wine as an alcoholic beverage made by the fermentation of grape juice or other sugar-containing substrates including honey, sugarcane, fruit juices, and other plant juices containing sugars, such as palm tree sap, floral extracts, and Agave, the century cactus plant [5]. So, the terms rice wine, orange wine, … are also usual. However, if the term is used alone, it must be applied only to the product resulting from the fermentation of the grape juice.

In 2022, according to the OIV, 7.30×10^6 ha of vines, allowed the production of 258×10^8 L of wine around the world [6]. This amount changes every year, depending on various circumstances like occasionally unfavorable climate conditions.

The two main biotechnological processes associated with wine production are alcoholic fermentation (AF), conducted by yeasts, and malolactic fermentation (MLF), by lactic acid bacteria. Alcoholic fermentation is the primary fermentation during winemaking. Throughout the AF, the fermentable sugars of the must, mainly glucose and fructose, are transformed into ethanol, carbon dioxide, and several other compounds contributing to the global taste and aroma of the wine. They belong to several chemical families: organic acids, higher alcohols, aldehydes, volatile fatty acids, ethyl esters and acetates, *etc.* [7, 8]. In practice, in winemaking, a must containing around 170 g/L of hexoses, will yield a wine with an alcoholic strength, by volume, of about 10% [9]. Malolactic fermentation (MLF) is a secondary fermentation in which L-malic acid is transformed into L-lactic acid and carbon dioxide, mainly. The main consequences of the MLF are the decreasing of the wine acidity and a subtle modification of the aroma, *i.e.* it may bring favorable organoleptic properties to the wines [9]. In terms of acid conversion, the fermentation of 1 g of malic acid per liter reduces the total acidity, expressed as tartaric acid, by approximately 0.6 g/L [9].

Normally, MLF starts when AF has finished, but co-inoculation of yeasts and lactic acid bacteria is an emerging trend in winemaking as it may reduce the length of the overall process [10].

Nevertheless, the process of winemaking includes several other steps before and after the fermentation processes [9, 11]. **Figure 1** presents the generic processes for making white and red wines, including the fermentation stages, the processes for preparing the must and finishing the wine before bottling, and also the residues, by-products, and liquid effluents generated. Although a few products are added to the must and/or wine, several residues are rejected, either as liquid or solid wastes [12].

White wine is usually produced by alcoholic fermentation of a clarified grape must. Malolactic fermentation may also occur in some wines. To obtain the most, after harvesting, and eventually selecting the bunches, the grapes should be crushed and pressed before the juice is clarified either by gravity or by dynamic processes—centrifugation, filtration, or flotation; pre-fermentative skin maceration is sometimes applied. Before alcoholic fermentation, the must usually need some specific preparation, depending on its initial composition and on the desired characteristics of the resulting wine. Sometimes the total must acidity may need adjustment of either increasing (acid addition, using for example tartaric acid) or decreasing (acidity reduction, using for example $CaCO_3$) [13]. The addition of enzymes (pectinases) accelerates particle sedimentation and helps the clarification of the grape must; glycosidases may be used to enhance varietal flavor [14, 15]. Sulfur dioxide (SO_2) is added to the grape must prevent oxidation and growth of wild yeasts and bacteria. To promote alcoholic fermentation, selected dry Saccharomyces cerevisiae yeasts are usually applied as fermentation starters, as this eases the control of the fermentation and can bring to the final product specific aroma compounds [9, 16]. A temperature

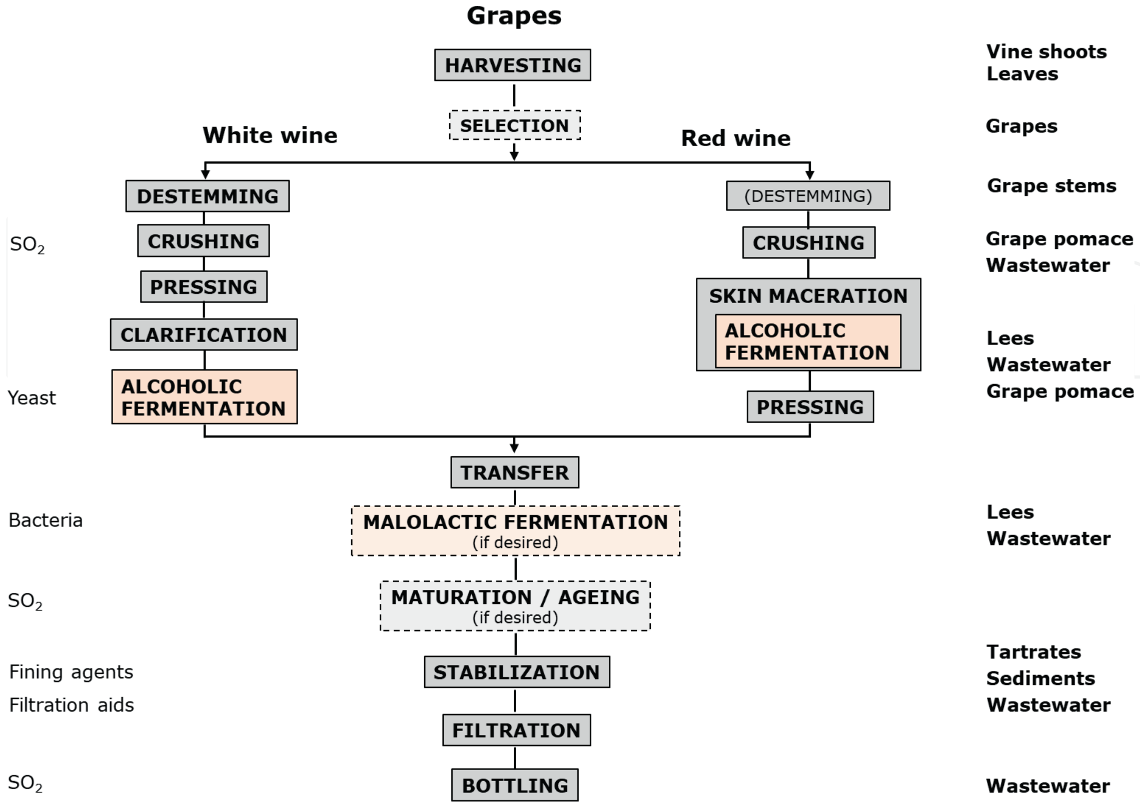

Figure 1.
Generic biotechnological process of winemaking, including waste and by-products generated.

of 18°C constitutes a good compromise between the fermentation rate and the final quality of the product. Recently, the use of non-*Saccharomyces* yeasts, either used singly or combined with S. cerevisiae (mixed or sequentially applied), became a way to obtain sensory distinct and more complex products [17, 18]. MLF, when desired, takes typically place after AF, in environmentally appropriate conditions, by inoculation of lactic acid bacteria, usually Oenococcus oeni. Then, the wine must be stabilized and clarified before bottling; a maturation step may also occur.

Contrarily to white wine, the fermentation of red wines is accompanied by maceration, to maximize the extraction of color (and other relevant compounds) from the grape pomace (mainly skins). The length and intensity of the macerations are very important and depend on the grape variety and the desired type of wine to be produced [9, 16]. In order to facilitate the extraction of coloring matter, temperatures around 25°C are used. Moreover, unlike white wines, red wines usually undergo malolactic fermentation and are aged (frequently in oak barrels) before bottling.

Rosé wines are made from red grapes, by alcoholic fermentation of the must that results from the immediate pressing, or that results after a slight/controlled skin maceration; the grape variety and the maceration time influence the shade of the final product [9].

3. Reutilization and valorization of winemaking residues

In the framework of the circular economy, obtaining natural components from food waste has gained interest. The disposal of winemaking residues in the environment is a serious concern and as such, in recent years, attracted much attention of the scientific community in an effort to find profitable and sustainable solutions for their reutilization and valorization. The main winemaking residues that will be addressed in the following rows are vine pruning, grape stems, grape pomace, and lees.

3.1 Vine pruning

Vine pruning is fundamental for the vineyards. It is a practice where shoots, branches, and herbaceous parts are cut to achieve good harvest and quality grapes. There are different types of grape pruning with distinctive characteristics that influence the vine and consecutively the produced grapes. Vine pruning residues (VPR) are a lignocellulosic material and even though it is known to have interesting added-value compounds with different bioactivities, this material is still economically underutilized [19]. Lignocellulosic residues are a possible sustainable substitute for fossil-based fuels, chemicals, and materials. It was concluded that VPR contains more lignin than other renewable sources like wheat straw and corn stalks. The proximal composition of VPR was found to be as follows: cellulose from 24.8 to 32.4%, hemicellulose from 9.6 to 13.8%, and lignin from 23.7 to 32.4% [20]. Moreover, VPR is a rich source of polyphenol compounds.

VPR can be used for different purposes (**Table 1**). For example, it was used as raw material for ethanol production by hydrothermal treatment, also known as autohydrolysis [21]. The autohydrolysis was used in two sequential stages in an attempt for the integral valorization of VPR. With the proposed method, xylooligosaccharides, phenolic compounds, and ethanol were obtained. In summary, 69 kg of value-added compounds were obtained from processing of 100 kg VPR. In the study from Gullón *et al*., autohydrolysis combined with extraction with ethyl acetate was evaluated as

Compound	Method used	Reference
polyphenols	Ohmic heating	[19]
ethanol, xylooligosaccharides, polyphenols	autohydrolysis	[21]
lactic acid, furfural	Saccharification, fermentation	[22]
polyphenols	microwave-assisted extraction, subcritical water extraction, conventional extraction	[23]
polyphenols	microwave-assisted extraction	[24]
particleboard	direct use	[25]
activated carbon	physical, chemical activation	[26]
monomeric sugars, furfural, HMF, formic acid, lactic acid	enzymatic hydrolysis	[2]
solid biofuel	burning	[27]
oligosaccharides, polyphenol compounds	autohydrolysis followed by ethyl acetate extraction	[28]
Energy source	catalytic combustion	[29]

Table 1.
Valorization of vine pruning residues.

the valorization process of VPR [28]. Oligosaccharides and polyphenol compounds were obtained with the suggested process.

A biorefinery concept was used for the production of lactic acid and furfural from VPR. Moreover, the life cycle assessment of the process was performed on the selected scenario. It was concluded that with this scenario there were significant reductions in climate change, fossil fuel depletion, freshwater ecotoxicity, and human toxicity impacts compared to their counterfactual systems [22].

VPRs are rich in polyphenol compounds and frequently are used for the extraction of these valuable compounds. Polyphenols have various biological activities like antioxidant, anti-mutagenic, anti-inflammatory, antimicrobial, and anti-carcinogenic properties [19]. The composition of the recovered phenolic compounds from VPR depends on grapevine variety, age, and growth conditions. Moreover, the extraction yield and type of extracted phenolics depend on the temperature, time, and solvent composition used in the experiments. The phenolic composition of extracts from VPR from the grape varieties Touriga Nacional and Tinta Roriz were evaluated [23]. Gallic acid, catechin, myricetin, and kaempferol were the main polyphenol compounds found in the extracts. Moreover, the extracts demonstrated high antioxidant activity and inhibitory activities against α-amylase and acetylcholinesterase enzymes, showing their potential to be used in the treatment of Alzheimer and diabetes's diseases [23]. In another study, the main polyphenol compounds identified in the extracts made with microwave-assisted extraction were apigenin and ellagic acid [24]. The main polyphenol compounds found in the ethyl acetate extracts of VPR were vanillin, acetovanillone, guaiacylacetone, syringaldehyde, and acetosyringone. The extracts had antioxidant and antimicrobial activities against both Gram-positive and -negative bacteria [28].

In other studies, VPR is used directly, like for example in the construction of particleboards. The experimental three-layer boards where wood particles from the core part were substituted with 50% of VPR demonstrated good properties. However, the use of vine pruning particles as surface material should be excluded as it deteriorates [25]. VPR was used directly as solid biofuel inside the vineyard. The idea of the project was to use VPR as solid chips for the boilers inside of the vineyards, replacing the pine pellets that are usually used. This change in solid biofuel decreased the total CO_2 emission of the vineyard, and consecutively its carbon footprint. It was calculated that the proposed process brings economic savings for the vineyard [27]. The high combustion efficiency of VPR was also obtained using catalytic combustion (Pd catalyst) in a conical spouted bed combustor [29].

VPRs were used after being transformed into activated carbon and applied in wines as a fining agent. The produced activated carbon was able to decrease the presence of unpleasant aromas, as well as to alleviate the negative effects of browning in a white wine [26].

An integrated biorefinery concept was applied with the objective of reusing all the winery waste streams. VPR were subjected to hydrothermal pretreatment followed by enzymatic hydrolysis. The obtained compounds depended on the severity of the treatment of the material and included the compounds glucan and xylan (at milder pretreatment conditions), furans (furfural, HM-hydroxymethylfurfural), and organic acids (formic, lactic) [2].

3.2 Grape stems

The grape stems (GSs), also known as grape stalks, form the skeleton of the grape bunches. GS is obtained during the destemming process. It is a lignocellulosic material with the following proximal composition: 34% lignin, 36% cellulose, 24% hemicellulose, and 6% tannins [30]. The high contents of lignin and tannins make the grape stems a challenging material for processing and reutilization [30]. Compared to grape pomace and seeds GS has fewer bioactive molecules, but it is still an important source of antioxidant compounds [31].

At the same time, it is considered that using the GS exclusively to produce ethanol is not a cost-effective and beneficial process. In this context GP was exploited as biorefinery biomass for the production of second-generation ethanol, as well as added-value compounds including cellulose, hemicellulose, lignin, and cellulose nanocrystals (**Table 2**) [31].

GS were treated physically (heat process) and chemically (mercerization) with the intuition to be included in biocomposites for the production of new products that can be used in industries like packaging, aerospace, automotive, and construction [32]. In this context, GS was used as a primary source in the process of making highly porous bricks. The obtained total porosity and pore dimensions enhanced the durability and thermal insulation properties of the produced bricks. With respect to the same type of clay, bricks produced with GS decreased heat transmission by around 40% [33]. Another utilization for GS in biocomposites formula is as filler in bioplastics while polybutylene succinate was the basic polymer. The obtained product demonstrated improved mechanical properties, and lower production costs [40]. GS was, also, used directly as a solid substrate for the growing of R. oryzae *NCIM 1299* in a fermentation process intended to produce lactic acid [39].

The antioxidant extracts of GS were considered a promising replacement for sulfur dioxide in wine preservation. However, the authors concluded that before the implementation of this process in the wineries, additional studies should be carried out [35]. The polyphenol compounds present in the GS have the capacity to bond with the iron vacant orbitals protecting them from corrosion. In this context, the extracts

Compound	Method used	References
lignin, sugars, tannins	dilute sulfuric acid, ethanol organosolv, wet oxidation,	[30]
ethanol, cellulose, hemicellulose, lignin, cellulose nanocrystals	acid and enzymatic hydrolyses	[31]
modified grape stems	heat process mercerization	[32]
to produce porous bricks	direct use	[33]
(E)-resveratrol	photo-molecularly imprinted sorbent	[34]
sulfur dioxide replacement	extraction	[35]
corrosion inhibitor	water extraction	[36]
polyphenols	extraction	[37]
tannins	microwave extraction	[38]
solid substrate for fungi growth	direct use	[39]
as filler in biocomposites	direct use	[40]
succinic acid	alkaline and acid pretreatment, enzymatic hydrolysis	[41]
adsorbent	direct use, activated carbon	[42, 43]

Table 2.
Examples of possible valorization of grape stem residues.

of GS were used as corrosion inhibitors of mild steel in 0.5 mol/L NaCl. The GS extract applied at 400 mg/L was found to provide maximum protection of 88% [36].

The potential application of GS extracts in the cosmetic, pharmaceutical, and food industries was also evaluated. The analysis of the extracts confirmed the presence of polyphenol compounds with catechin showing the highest concentrations. Moreover, the extracts had diverse bioactivities including antioxidant, anti-inflammatory, and anti-aging [37]. GS was directly applied in the vinification of the grapes from the variety Bonarda with the objective to increase the tannin content of the resulting wine. The result demonstrated that the use of GS in the fermentation process modified the chromatic characteristics and phenolic composition, improved the color stability, and changed the volatile and polysaccharide profile of the produced Bonarda wines [38].

GS can be used as a raw material for the production of succinic acid. Succinic acid has many applications in the pharmaceutical, agricultural, food, and chemical industries. The proposed process valorization included alkaline and acid pretreatment of the stems, followed by enzymatic hydrolyses. The sugar-rich hydrolysate was further used as fermentation broth for the production of succinic acid [41].

GS contains various functional groups (tannins, tartrate, organic acids, *etc.*) that make it a good candidate for adsorbent, that can be directly used or in the form of activated carbon. As such GS was successfully used for the removal of caffeine and methylene blue from wastewater [42, 43].

It is to refer to the fact that, grape stem extracts were evaluated for their multiple biological activities like anti-cancer (breast, colon, renal, and thyroid cancer cells) [44], anti-microbial (including digestive pathogens) [45], also against ultraviolet irradiation [46], antioxidant, anti-inflammatory, anti-aging, and others [37]. In this context, further studies are needed to find out and understand the full potential of this waste material and to project its further utilization.

3.3 Grape pomace

Grape pomace (also known as grape marc) is the residue after pressing the grapes. It is a mixture of grape skins, grape seeds, and some grape stems. Traditionally grape pomace is used for ethanol distillation, animal feeding, or spread in the land. The grape pomace distillation and resulting spirits are an important industrial activity in countries like France and Italy. High amounts of bioactive compounds are present in GP, especially polyphenols. Their concentration and presence depend on numerous variables like type of grape variety, type of vinification process, geographic region, and year of harvest [47].

Grape pomace (GP) was used for the extraction of oleanolic acid, a natural triterpenoid with antidiabetic properties (**Table 3**) [48]. Besides oleanolic acid other compounds like polyphenolic compounds, anthocyanins, minerals, and amino acids were also identified in the GP extracts. The most abundant polyphenols found in the extracts were catechin, epicatechin, caffeic acid, and quercetin. A sustainable production process of ethyl hexanoate (ester with flavor of pineapple) from GP was evaluated. GP was used for the production of hexanoic acid that was further converted to ethyl hexanoate [49]. The proposed process demonstrated to be a possible alternative to fossil-derived hexanoic acid.

In the context of circular economy and waste reutilization, the use of green technologies is the best possible scenario. Aqueous solutions of surfactants are green substitutes for organic solvents and were used for the extraction of polyphenols from GP [50]. The main extracted polyphenols were catechin and quercetin. Catechin and quercetin were also the main polyphenol compounds found in GP extracts made with non-ionic surfactants [55]. The study was conducted with 11 different surfactant solutions and demonstrated that the structure specificities of the surfactants influence the extraction efficiency of the polyphenols.

Compound	Method used	Reference
oleanolic acid, polyphenols, amino acids, anthocyanins	ethanol extraction	[48]
polyphenols, fibers, polyunsaturated fatty acids, minerals and protein	ethanol extraction	[47]
hexanoic acid	fermentation	[49]
polyphenols	surfactants extraction	[50]
anthocyanins	ultrasound-assisted extraction	[51]
anthocyanins	extraction with eutectic solvents	[52]
substitute for wheat flour	direct use	[53]
pectin	conventional, microwave-assisted, and pulsed ultrasound-assisted extraction	[54]
polyphenols	non-ionic surfactants extraction	[55]
animal feed	direct use	[56]
energy	pyrolysis	[57]
polysaccharides	extraction	[58]

Table 3.
Valorization of grape pomace residues.

The eco-friendly ultrasound-assisted extraction method was used to obtain anthocyanins from red GP [51]. Anthocyanins are known to have many health benefits, for this reason in our days anthocyanin supplements are an important part of the nutrition market. Anthocyanin isolation from agro-industrial wastes is attracting much attention. Besides their bioactive properties, anthocyanins are also used as natural colorants. For this purpose, anthocyanins were extracted from GP using eutectic solvents [52]. The proposed method of isolation and stabilization of the extracted anthocyanins had low environmental impacts and economic costs compared to the conventional extraction with solvents.

GP, in powder, can be used directly in the elaboration of cakes, as a substitute for wheat flour. Cakes produced with 4% GP powder showed good sensory quality with enhanced nutritional properties, once the GP powder provided the cakes with polyphenolic compounds [53].

GP was also used for the extraction of pectin applying green technologies, like microwave and ultrasound-assisted extractions. Pectin is a polysaccharide found in the plant cell walls. Normally it is extracted from apples pomace and citrus peel using organic or mineral acids. The use of different extraction methods resulted in extracted pectin with diverse structural characteristics [54]. However, it was concluded that pectin from GP has the potential to be applied in different fields including the food industry. In another study, the extracts of GP were successfully applied as antimicrobial additives in polypropylene food packaging. The obtained materials demonstrated antimicrobial activity against Gram-negative (Escherichia coli) and Gram-positive (Bacillus subtilis) bacteria [59].

GP is rich in polysaccharides, especially the GP from white grapes. GP from red grapes is only liberated after the fermentation of the juice, so it contains less pulp and residual sugars, than the white GP. However, polysaccharides may be also obtained from red GP. The most abundant polysaccharides in extracts made with hot water were arabinose, xylose, mannose, glucose, and galactose [58].

Cheese made from the milk of ewes on a diet formula that included GP had improved sensory characteristics. GP supplement mainly affected the aromatic profile of the cheese [56].

GP was also evaluated as an energy source. The proposed idea is to use the energy obtained from GP pyrolysis in the food processing plants to reduce the final cost of energy [57].

As a final remark, we can say that grape pomace is a versatile source of different compounds and products that can be used in the food industry, in the pharmaceutical and cosmetics industries, in agriculture, as well as energy sources.

3.4 Lees

Wine lees are one of the main byproducts of the wine industry. This sludge is essentially made up of dead yeast, which precipitates at the bottom tanks after the fermentation process has taken place [60–62]. According to Galanakis, 85.7 t (dry basis) of wine lees are generated for every 1000 m^3 of wine produced [63].

Since lees contain large amounts of polysaccharides, lipids, proteins, and other compounds with high demand for oxygen, their deposition to the environment, causes serious pollution problems, due to the high organic content and a low pH. These characteristics also make their direct use in agricultural practices inappropriate, such as the production of compost and use for animal feed.

On the other hand, since this by-product contains a wide variety of value-added compounds, the investigation of potential recovery routes has gained relevance. In this way, the deepening of this strategy would not only avoid serious environmental problems but would also reduce the costs associated with its deposition [64]. More specifically, wine lees contain both liquid and solid fractions. The first is called vinasse and contains bark, part of the seed, and dead yeast, consisting of the spent fermentation broth. In turn, the solid fractions contain organic and inorganic salts, grain, seeds, cellulose, hemicellulose, and lignin. Both fractions have the potential to produce added value by-products, with high economic relevance [60, 61].

Thus, in order to avoid the conventional applications of this by-product (agriculture and animal feed), which are not appropriate and generate environmental problems, several approaches have been applied and several studies have been carried out in order to find effective, sustainable, and economically viable alternatives.

On an industrial scale, only ethanol and tartaric acid extraction have been applied. From the wine lees distillation process, it is possible to recover ethanol and produce distilled beverages [65]. The by-product obtained from distillation (vinasses) contains several value-added components with the potential to be extracted.

Wine lees are the major source of tartaric acid and the most valuable component that can be extracted from vinasses [66]. This acidifier is widely used in the food and beverage industry, as well as in the pharmaceutical, cosmetic, and chemical industries [67, 68]. Conventional processes for obtaining tartaric acid (precipitation, crystallization, acidification, ion exchange, *etc.*) are associated with disadvantages at environmental and economic levels, essentially due to the production of calcium sulfate as waste. In this way, new studies have been carried out to try to overcome these problems, trying to reduce the consumed energy and the use of chemicals [67, 69]. New technologies being tested include membrane processes and microwave-assisted and ultrasound-assisted extraction techniques, showing improved results in terms of extraction yields [67, 70, 71].

In addition to these more developed strategies, there are other promising possibilities that have been studied and tested. One of them is the biotechnological application of remaining lees as a culture medium for lactic acid bacteria [68]. Studies have shown the possibility of integrating the production of microbial substrates from this by-product, with the extraction of ethanol and tartaric acid, in order to extract the greatest number of components and make the processes viable [64, 68].

Furthermore, the cell walls of mannoproteins and β-glucans from wine lees have been explored, proving to be promising for various types of applications, namely the food industry (emulsifier, fat replacers, cholesterol reducer, antioxidant) and viticulture (foam, mouthfeel enhancer). Extraction methods can vary between physical, chemical, enzymatic methods, and a combination of these [72, 73]. In turn, Iseppi studied the development of methods for yeast glycocompounds extraction from wine lees, through physical (autoclave and ultrasonication) and enzymatic methods, demonstrating their possibility of use as winemaking additives [74].

Moreover, wine lees present a valuable opportunity as rich sources of anthocyanins and other polyphenols, showcasing the strong potential for use within the food, cosmetics, and pharmaceutical industries. This ability to foster health benefits is attributed to their well-recognized properties as antioxidants, antimicrobial agents, anti-inflammatory substances, and promoters of cardiovascular well-being [75].

Additionally, the production of biogas has been tested as a potential application of the solid fraction of wine lees. This strategy involves anaerobic co-digestion of wine lees by Escherichia coli under mesophilic and thermophilic conditions [76].

Compound	Method used	Reference
ethanol	distillation	[77]
polyphenols	organic solvents	[75]
polyphenols	microfiltration	[78]
β-glucans	extraction using NaOH	[73]
microbial media	preparation for microbial media	[68]
polyphenols, polysaccharides	ultrafiltration and nanofiltration	[70]
ethanol, tartaric acid, polyphenols, microbial media	cation exchange resin	[79]
tartaric acid polyphenols	nanofiltration	[67]
ethanol, tartaric acid, polyphenols, microbial media	extraction and preparation for microbial media	[64]
biogas	anaerobic digestion	[76]
yeast glycocompounds	ultrasonication, enzymatic, autoclave	[74]

Table 4.
Summary of the papers that studied valorization approaches for wine lees.

In short, wine lees have great potential for extracting value-added compounds. The investigation of the methods to be adopted must be deepened in order to optimize the extraction efficiency. The development of integrated approaches aimed at extracting various types of compounds for application in different sectors would be an asset to promote the valorization of wine lees, applying the circular economy in this sector and promoting environmental and economic sustainability.

Table 4 presents the possible wine lees valorization strategies that have been studied.

As final remarks about the extraction methods used to obtain valuable products, one can see that there are various methods used. The right choice of method will depend on the desired result as well as the existing conditions in each laboratory. It is evident that the simplest and the easiest method to be implemented and used is the conventional heat extraction method. Clearly, the method of extraction to be applied will depend on the nature of the desired final compounds. The best choice is that the used method is environmentally friendly and of a low cost, *i.e.* without aggressive solvents and methods that spend a high amount of energy and are time-consuming. Some methods used additional consummatives like enzymes (enzymatic hydrolase) or membranes. Others required the use of specialized apparatus like ultrasound or microwave extraction methods. In this sense, many times the chosen method will also depend on the possibilities of the laboratory to acquire equipment and apparatus.

4. Conclusion

Wine residues are rich sources of various compounds of interest like polyphenols, dyes, carbohydrates, organic acids, and others. As such wine residues can be a cheap alternative for the development of new products, functional foods, pharmaceuticals, and cosmetics. Regardless of the many existing studies on the valorization of wine wastes, the proposed processes have not been widely implemented in the winemaking industry so far. There is still much work to be done until wine residues gain an established recovery pathway that brings economic benefits.

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Conflict of interest

The authors declare no conflict of interest.

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