

Proceedings

Sustainable Exploitation of By-Products of Vitivincultural Origin in Winemaking [†]

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† Presented at the 1st International Electronic Conference on Applied Sciences, 10–30 November 2020;

Available online: <https://sciforum.net/conference/ASEC2020>.

Published: 10 November 2020

Abstract: Grapes are cultivated globally with the total area under vines reaching 7.4 million hectares in 2018 and the global wine market is expected to increase to USD 423 billion by the end of 2023. However, winemaking produces large quantities of by-products/wastes like grape pomace (GP; the residue of pressed grapes), wine lees (WL; the residue accumulating in vessels containing wine after fermentation) and vine shoots (VS; generated during the pruning season in the vineyard). Exploitation of agro-industrial side-streams, wastes and residues, such as WL, GP and VS, is an issue of vital importance to global, good environmental governance. As WL and GP constitute valuable sources of nutrients and VS source of cellulose fibers, their use for novel products with applications in winemaking is of major importance. In the present study the recent trends in sustainable exploitation of such by-products for application in winemaking are presented. WL consists mainly of ethanol, tartaric acid and yeast cells and it is usually used for the recovery of these bioactive compounds and as a nutrient supplement of lactic acid bacteria and yeasts growth. GP has been used for the recovery of phenolic compounds, as a substrate for alcohol production and as fertilizer in the vineyard. New trends include its use for eliminating unwanted wine compounds (like ochratoxin A and pesticides) and as a sustainable fining agent of wines (in order to modify its sensory features such as astringency, bitterness, and mouthfeel). Finally, VS has been used as biochar and for nanocomposite film production.

Keywords: grape pomace; wine lees; vine shoots; grapes; ethanol; sustainability

1. Introduction

Grape is a fruit that is cultivated all over the world, with an annual production of 77.8 million tons for 2018 (57% of which were wine grapes), while for the same year annual wine production was 29.2 billion liters [1]. Global wine sector is continuously expanding, and in 2017 it was estimated approximately 302 billion USD, while being expected to increase to approximately 423 billion USD by the end of 2023 [2]. Within the wine sector however, besides wine production, large quantities of by-products are also produced. The main winemaking by-product is considered to be grape pomace (GP), which is defined as the residue of the pressed grapes. Given the fact that world production of grapes in 2018 was 77.8 million tons and that 57% of which were used in winemaking, we can conclude that approximately 6 million tons of GP would be produced as waste and would require treatment [3]. Another by-product is wine lees (WL), which consists of the residue accumulating after fermentation in vessels containing wine. According to studies, 0.06 tons of WL are produced per ton of crushed grapes and therefore in 2018 the total amount produced worldwide was around 2.66 million tons [1,4]. Lastly, as far as the vineyard is concerned, vast amounts of wastes are generated

during the pruning season, which are known as vine shoots (VS). Up to 2×10^7 tons are produced annually, which is translated to approximately 1.4–2.0 tons per hectare [5]. Due to the large quantities of these by-products, both in vineyards and wineries, high concerns have risen among the industrial and scientific community regarding the high environmental risks that come with their disposal.

2. Vitivinicultural By-Products and Composition

As mentioned above, GP is the main winemaking by-product, which consists mainly of peels (skins), seeds and stems (which account for about 13% of the grape) that are left behind after the crushing, draining and pressing processes of winemaking [6]. WL are described by the EEC regulation No 337/79 as “the muddy residue accumulating in wine vessels after fermentation or during the storage of wine, dried or not”. WL contain mainly yeast cells, tartaric acid, inorganic matter and phenolic compounds [7]. VS are described as the residue after the cutting of vineyard branches and approximately 3.5 tons are produced per hectare [8]. Table 1 present the major physicochemical characteristics of each by-product.

Table 1. Chemical composition (% w/w) of vitivinicultural by-products.

GP	WL	VS
pH: 3.4–5.4 [9]	pH: 3.6–7.2 [9]	Moisture: 7.9–8.4% (DM) [14]
Polyphenols: 0.09–1.36 (DM) [9]	Polyphenols: 0.19–1.63 (DM) [9]	Ash: 3.0–3.8% (DM) [14]
Dietary fiber: 19–38 (DM) [10]	Protein: 14.5–15.7% (DM) [12]	Holocellulose: 64.2–69.6% (DM) [14]
Total nitrogen: 1.0–1.7 (DM) [10]	Lipids: 5.0–5.9% (DM) [12]	Lignin: 19.3–21.8% (DM) [14]
Sugars: 15–33 (FM) [10]	Sugars: 3.5–4.8% (DM) [12]	Pentosans: 18.4–23.6% (DM) [14]
Lipids: 0.4–1.0 (FM) [10]	Tartaric acid: 24.5–24.7% (DM) [12]	Lipids: 2.4–6.7% (DM) [15]
Ash: 1.8–2.4 (FM) [10]	Ash: 10.5–10.6% (DM) [12]	Proteins: 4.0–5.3% (DM) [15]
COD: 610 g O ₂ kg ⁻¹ [11]	COD: 72–323 g kg ⁻¹ [13]	

GP: Grape Pomace; WL: Wine Lees; VS: Vine Shoots; DM: Dry Matter; FM: Fresh Matter; COD: Chemical Oxygen Demand.

3. Applications

Exploitation of agro-industrial side-streams, wastes and residues, such as GP, WL and VS, is an issue of vital importance for global good environmental governance, which is directly connected to environmental, economic and social impacts. As GP and WL constitute valuable sources of nutrients and VS a good source of cellulose fibers, all of these by-products can be utilized for the production of novel products in winemaking, but also for enhanced food products with potential functional properties (Table 2).

Traditionally, GP has been mainly used for the production of a substrate for alcoholic fermentation. Consequently, the distillate produced can be marketed, with numerous spirits with different names being produced around the world [16,17]. Other exploitation methods include its use as a fertilizer or as animal feed [18,19]. However, all these valorization methods present several drawbacks, the major of which is failing to exploit the full market potential of GP [20]. For this reason, along with advances in science and technology, new methods for the exploitation of GP have been developed. Firstly, it has been used as an ingredient for the production of novel products with new functional properties and health benefits, such as beverages and bakery products [21]. Moreover, a trend has emerged that includes the use of GP for the elimination of unwanted compounds, such as ochratoxin A in wine [22] and as a fining agent in synthetic media [23] and wine for the modification of sensory attributes [24]. Specifically, the potential of GP fibers for fining red wines has been

investigated, following the trend of alternatives to animal-derived proteins [24]. Results showed that this treatment could be applied in winemaking, with further studies being needed for the improvement of effectiveness.

Due to the high concentrations of tartaric acid and ethanol, WL have been mainly used as a raw material for the extraction of these substances, whereas on the other hand, they cannot be used as animal feed due to high polyphenol content [25]. In addition, the production of lactic acid and xylitol from WL employing *Lactobacillus rhamnosus/Lactobacillus pentosus* and *Debaryomyces hansenii*, respectively, has been also studied [26–28]. The potential use of WL as a supplement for cell growth has also been referred, as the solid fraction of WL, which consists mainly of yeast cells, can be converted into nutrient-rich fermentation supplements [29]. The chemical composition of WL (carbohydrates and nitrogen compounds, yeast metabolites and vitamins), render them a promising supplement that can simulate yeast extract and could consequently be used in formulating culture media for the growth of winemaking yeasts [30].

Lastly, VS traditionally remain in the vineyard and they can be used as organic fertilizer or as a substrate for the mushroom industry [31]. The extraction of valuable compounds from VS has been investigated [4], whereas the production of nanocomposite materials from VS has also been studied [32]. The results appear promising as the produced material presents higher thermal stability in comparison with cellulose nanocomposites from other sources, thus showing the potential to be used in novel nanocomposite films with enhanced mechanical properties. Generally, studies on the exploitation of VS focus mainly on the production of solid biofuels [8] and biochar [33]. In the context of winemaking, VS-derived biochar could potentially be used as a fertilizer in the vineyard, while biofuels could provide the energy required for wineries to operate, promoting the sustainability of the vitivinicultural sector. However, possible applications of VS in winemaking are not restricted to the methods mentioned above. The potential of VS chips to be used as an enological additive similar to oak chips has been investigated, contributing to the chemical, sensory and antioxidant characteristics of wine [34,35]. Moreover, the foliar application of VS extracts on grapevines as a “viticultural biostimulant” has also been studied [36]. Produced wines presented enhanced quality and interesting sensory characteristics.

Table 2. Major current applications for the valorization of vitivinicultural by-products (bullets in bold indicate possible applications in winemaking).

GP	WL	VS
<ul style="list-style-type: none"> • Absorbents (e.g., removal of toxins) • Animal feed • Distillation/spirits • Fertilizer • Fining agent • Functional ingredient 	<ul style="list-style-type: none"> • Ethanol (extraction) • Fermentation substrate (e.g., lactic acid, xylitol production) • Supplement for cell growth • Tartaric acid (extraction) 	<ul style="list-style-type: none"> • Foliar additive • Nanocomposites • Organic fertilizer • Production of solid biofuels and biochar • Substrate for mushroom production • Wood chips

GP: Grape Pomace; WL: Wine Lees; VS: Vine Shoots.

4. Conclusions

As a food production process, winemaking generates large quantities of by-products, which should be considered as potential materials for valorization. According to that, EU legislation enforces the proper treatment of these by-products, while encouraging their valorization besides energy recovery. For this purpose, they should be reused and exploited in the context of added-value products, although it is certain that further studies are needed in order to optimize such exploitation processes. In addition, they can also be utilized in food processing and packaging, with results from studies being very promising. The applications mentioned in the present study indicate the potential of vitivinicultural by-products to be used in various industries. However, the potential of these by-products is clearly shown, as they are rich in bioactive substances and they can be exploited in

numerous ways, while supporting sustainable agricultural production. As a matter of fact, it appears that they could be exploited within winemaking and grape cultivation, in different stages during production, promoting the sustainability of vitivinicultural sector.

Author Contributions: conceptualization, P.K.; writing—original draft preparation, E.K. and P.K.; writing—review and editing, P.K.; supervision, P.K.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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