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Sustainable options for the utilization of solid residues from wine production

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ABSTRACT

The efficient use of solid organic waste materials is an issue of particular importance for the wine industry. This paper focuses on the valorization of grape marc, the major component of winery organic waste (60–70%). Two methods were designed and compared: combustion to generate electricity, and the pyrolysis for the production of bio-char, bio-oil, and bio-gas. Each of these processes was analysed to determine their economic and environmental viability. The flow-sheeting software, ASPEN PLUS, was used to model the two cases. Data from the simulations was used to inform techno-economic and environmental analyses. Pyrolysis was found to be the superior method of utilizing grape marc from both economic and environmental perspectives. Both pyrolysis and combustion exploit the energy content of the waste, which is not recovered by the traditional treatments, composting or distillation. In addition to the production of energy, pyrolysis yielded 151 kg of bio-char and 140 kg of bio-oil per tonne of grape marc. These products may be used in place of fossil fuels, resulting in a net reduction of carbon dioxide emissions. However, the potential deleterious effects resulting from the replacement of the traditional treatments was not considered. Investment in either pyrolysis or combustion had a negligible impact on the price of the wine produced for wineries with an annual grape crush larger than 1000 tonnes. Composting has significant economic advantages in wineries with a small grape crush of less than 50 tonnes.

1. Introduction

Humans have produced wine since the dawn of agriculture during the Neolithic period over 8000 years ago (McGovern, 2007). Since then, it has become an integral part of culture, society, and religion around the world. It is therefore no surprise that grapes were one of the earliest fruits to be cultivated and are now one of the most common fruit crops in the world (Myles et al., 2011). In 2014, the worldwide production of grapes was over 77 million tonnes (Statistics Division, 2013), the vast majority of which was used for the production of 28 billion liters of wine (Wine Institute, 2011). Because of the size of this industry, and the amount of agricultural land devoted to the production of wine it is important that the environmental impact of the industry is minimized (Christ and Burritt, 2013). The recent trend towards quality-focused, small wine producers presents a challenge as it has the potential to result in decreased efficiency and an increase in the environmental impact of winemaking (Iannone et al., 2016). An important aspect of wine production that has a significant impact on the overall efficiency and environmental impact of the wine-making process is the effective minimisation, management, and utilisation of waste streams (Musee et al., 2007).

Solid organic by-products of wine production include grape marc, stalks, wine lees, and sludge. These materials are often treated as waste with little or no value. Of these materials, grape marc is the major component representing ca. 62% of the total organic waste (Ruggieri et al., 2009). Grape marc typically has a high water content (ca. 60%), but on a dry basis is comprised of skin (ca. 51%), seeds (ca. 47%) and stalks (ca. 2%) Duba, 2015. However, the specific composition of grape marc is dependent on the type of wine produced. For some grapes the proportion of stalks has been shown to be as high as 11% (Bacic, 2003). This disparity can be linked to differences in the wine production process. Red wine production often sees the stalks removed separately before the pressing process, as shown in Fig. 1. As a result, the mass of grape marc accounts for between 11% and 22% of the grapes crushed for red wine production and 12–25% for white wine production (Bacic, 2003). Another difference between white and red wine production is that red wine grape marc typically has a higher alcohol content, but lower sugar content. Such differences in composition are reflected in the ultimate analysis of grape marc. Such analyses

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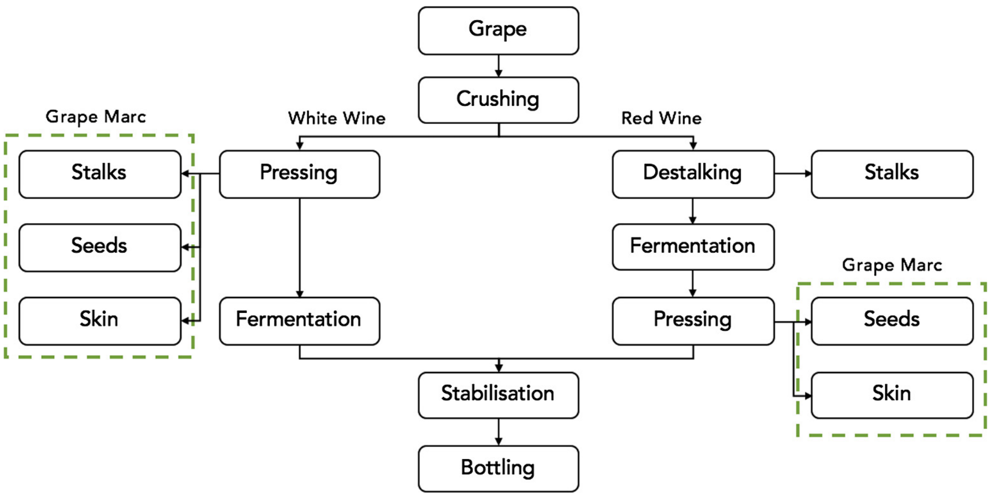

Fig. 1. Simplified wine production diagram detailing the source and composition of grape marc waste.

represent key data for the theoretical modelling of grape marc processing. However, as shown in Table 1, the ultimate analysis data from literature shows little difference in grape marc composition. Table 1 also shows ultimate analysis data from the Biomass Handbook (Hall and Kitani, 1989) which is widely accepted and used in similar studies (Domalski et al., 1986; Li et al., 2016).

In comparison to other solid hydrocarbon fuels that may be processed by either combustion or pyrolysis, such as coal, grape marc has significantly lower carbon content and higher moisture content. For example, Anthracite (a high rank coal) has moisture and carbon contents of 2.8% and 94.39%, respectively (Domalski et al., 1986). These differences are reflected in the differences in the lower heating values (LHV) of the two materials. Grape marc has as LHV of 6.00 kJ/g wb (wet bulb) (Rada and Ragazzi, 2012) and 19.14 kJ/g db (dry bulb) compared to 34.62 kJ/g for anthracite coal (Domalski et al., 1986). Due to its low energy content, grape marc is a low-grade fuel and produces a significant quantity of carbon dioxide per kilo-watt-hour (kWh) generated. However, these disadvantages are offset by the low-cost of grape marc, and because it is renewable and hence carbon neutral.

Generally speaking, the traditional treatment of grape marc includes the following methods: distillation, composting or landfill, combustion, gasification, and pyrolysis, which were summarized in Table 2. The precise distribution of grape marc handling is shown in Fig. 2 (Australian Wine Industry Association Incorporated, 2003).

Grape marc is traditionally distilled to produce grape marc spirits such as grappa (Fotakis et al., 2013). In Australia the majority of grape marc is processed by distillation. The South Australian Environmental Protection Authority (Waste Management Committee, 2001) estimated that approximately 90% of grape marc produced in South Australia undergoes distillation. However, due to a decreasing demand for the products of grape marc distillation, it has become an increasingly unattractive option for grape marc treatment. The European Council Regulation (EC) 1493/1999 on the Common Organization of the Wine Market dictates that grape marc waste must be sent to distilleries. However there is evidence that small wineries often disregard this law (Bustamante et al., 2008). Despite its wide-spread application, distillation does pose some problems. Storage of grape marc is a major concern due to the large quantities produced in a short period of time. (Faure and Deschamps, 1990) found that large quantities of stockpiled grape marc will undergo fermentation which results in the production of undesired products. Grape marc distillation produces grape marc spirits, exhausted grape marc and vinasse. Each tonne of grape marc produces approximately the same amount of exhausted grape marc, between 40 and 80 liters of spirit, and 400–1200 liters of vinasse (Newton, 2013; Larsson and Tengberg, 2014). Exhausted grape marc shares many of the disposal issues known for grape marc. Vinasse is a liquid waste product that is typically characterized by a low pH and high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) (Baez-Smith, 2006; Belhadj et al., 2013). These properties make vinasse a troublesome waste product which, if not treated, can cause salinization, sodification, and acidification of soil (Fuess and Garcia, 2014). Being a liquid waste product, treatment by combustion or pyrolysis is unattractive, where the pre-treatment processes required would be energy intensive and cause significant fouling (Larsson and Tengberg, 2014; Sheehan and Greenfield, 1980). Beyond distillation, the primary areas of interest for the use of grape marc is composting (Bertran et al., 2004) and feedstock (Baumgärtel et al., 2007). Other areas of research include the extraction of valuable chemicals such as polyphenols, biosurfactants, and antioxidants (Dwyer et al., 2014).

The trend towards high crop yields in agriculture has led to the exploration of a variety of organic and inorganic substrates as fertilizers. Composting offers a cheap and convenient method to treat winery waste to produce a product suitable for use as a soil conditioner. The composting of grape waste is widely studied (Ferrer et al., 2001) with consensus on the viability of the method to both manage grape marc and produce a worthwhile fertilizer (Bertran et al., 2004; Nogales et al., 2005). Composting also offers the benefit of carbon sequestration. A majority of the carbon is sequestered with a greenhouse gas (GHG) emissions of 1.31 kg

Table 1
Ultimate analysis for grape marc waste.

	C	H	O	N	Cl	S	Ash
Literature Range (Domalski et al., 1986; Li et al., 2016)	47.22–54.90	5.83–6.33	30.40–38.63	1.86–2.37	0.05	0.03–0.21	4.20–9.50
Biomass Handbook (Hall and Kitani, 1989)	52.91	5.93	30.41	1.86	0.05	0.03	8.81

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