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Abstract

Today, the annual global production of grapes surpasses seventy million tonnes. Of the grapes used toward winemaking, one fourth end up as pomace. In addition to pomace, vine pruning residues, stems and wastewater sludge contribute to the immense volumes of waste that for a long time has been considered as without value.

The aim with this literature study is to provide a deeper knowledge about the extent of waste from the wine industry. In addition, to investigate current and previous methods of by-product management, and evaluate the benefits and drawbacks of applying them. An additional aim is to present and evaluate more innovative uses that can be applied to utilize the full potential of the plant residues more efficiently. This is done to determine if innovative methods can add value to the industry while reducing the environmental impact. The previous, current, and potential future applications on wineries of different sizes is also evaluated. This is made to determine if the methods will be predominantly beneficial or detrimental to the production value.

Most common previous and current methods are incineration and landfills, both with harmful effect on the environment. Other current day methods of by-product management are the production of grappa, using grape pomace as feed and composting. The production of grappa and similar spirits hold great cultural and economic value to the producing countries, but the volume of pomace is only slightly reduced. Grape pomace as feed have been studied with various outcomes. Composting grape pomace is, despite the benefits, not as common as it should be. Few data are available on the proportion of wineries which compost their own residues, however, as an example, in the San Juan province in Argentina, only 5% of wineries compost their by-products.

New innovations for the utilization of plant residues include using grape pomace in construction and as an adsorbent of heavy metals. Bioactive compounds can also be retrieved from grape pomace, to be used as food additives or nutraceuticals. Antioxidants show great promise for counteracting coronary heart disease and in preventing lipid oxidation in meats.

The production of biofuels presents an option to fully exploit the potential of the plant residues. Producing fuels to reduce demand for externally sourced energy is found to benefit even vineyards with production below 50 tonnes.

Keywords: wine, waste, utilization, grapes, residue, pomace

Sammanfattning

Idag överstiger den globala produktionen av vindruvor 70 miljoner ton varje år. Av druvorna som används till vinproduktion slutar en fjärdedel som pressrester. Utöver pressrester bidrar beskärningsrester, stammar och avloppsslam till de enorma volymerna avfall, som under en lång tid betraktats som utan värde.

Syftet med den här litteraturstudien är att ge en djupare kunskap om omfattningen av avfall från vinindustrin. Därtill att undersöka nuvarande och tidigare metoder för hantering av biprodukter, och utvärdera fördelarna och nackdelarna med att tillämpa dem. En ytterligare målsättning är att presentera och utvärdera mer innovativa användningsområden som kan användas för att mer effektivt nyttja den fulla potentialen hos växtresterna. Detta görs för att se om nytänkande metoder kan bidra med värde till industrin och minska miljöpåverkan. De tidigare, nuvarande och möjliga framtida applikationerna på vingårdar av olika storlek utvärderas också. Anledningen är för att kunna avgöra om de är övervägande fördelaktiga eller menliga för produktionsvärdet.

De vanligaste metoderna har varit och är fortfarande förbränning och deponier. Båda dessa har en negativ påverkan på miljön. Andra metoder som används idag för att hantera biprodukter är tillverkningen av grappa, användningen av pressrester som foder, och kompostering. Tillverkningen av grappa och liknande spritsorter har stort kulturellt och ekonomiskt värde för de producerande länderna, men volymen av pressrester blir endast något reducerad. Pressrester som foder har undersökts med olika utfall. Kompostering av pressrester är trots många fördelar inte så vanligt som det borde vara. Uppgifter kring hur många vingårdar som komposterar sina egna restprodukter är bristande, men för att ta ett exempel, i San Juan provinsen i Argentina komposterar bara 5% av vingårdarna sina biprodukter.

Nya innovationer för att utnyttja växtresterna bättre är bland andra användningen av pressrester inom konstruktion och för att adsorbera tungmetaller. Det är också möjligt att extrahera bioaktiva ämnen från pressresterna, för användning inom funktionell mat eller som livsmedelstillsatser. Antioxidanter från pressrester visar stor potential för att motverka hjärt- och kärlsjukdomar, men också för att motverka oxidering av fett i kött.

Produktionen av biobränsle är ett lovande alternativ för att fullt nyttja potentialen hos växtresterna. Att producera bränsle för att minska behovet av externt införskaffad energi är fördelaktigt även för vingårdar med en produktion som understiger 50 ton.

Nyckelord: vin, avfall, utnyttjande, vindruvor, rest, pressrester

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Abbreviations

BCE	Before the Common Era
DM	Dry Matter
DP	Dry Pomace
GP	Grape Pomace
GPC	Grape Pomace Concentrate
GSE	Grape Seed Extract
VPR	Vineyard Pruning Residues
WP	Wet Pomace

1. Introduction

1.1 Background

Wine is a commonly alcoholic beverage enjoyed and appreciated worldwide. Proof of wine production has been found from as far back as 6000 BCE, in western Iran (McGee, 2004).

Since 2013, the total world production of grapes has exceeded 70 million tonnes (FAOSTAT, 2022). Of the grapes used toward wine making, roughly one fourth unavoidably ends up as pomace (Dwyer et al., 2014).

In 2019, wine represented the largest share of total alcohol consumed at 42.3% of the 8.98 litres of pure alcohol consumed by Swedes above the age of 15 (Trolldal & Åström, 2020). Estimating an average bottle of wine has an alcohol percentage of 8% this would imply that each Swede on average consume about 63 bottles of wine on a yearly basis (Appendix I). To acquire one bottle containing 750 ml of wine, 1 kg of grapes are used on average (Beres et al., 2017). That means every Swede contributes with about 16 kg of grape pomace each year (Appendix I).

The consumption of wine in Sweden has increased since the early 2000s despite that the average consumption of alcohol has decreased in the same time period and geographical location (Trolldal & Åström, 2020). Wine is thus seemingly a beverage still growing in popularity in Sweden.

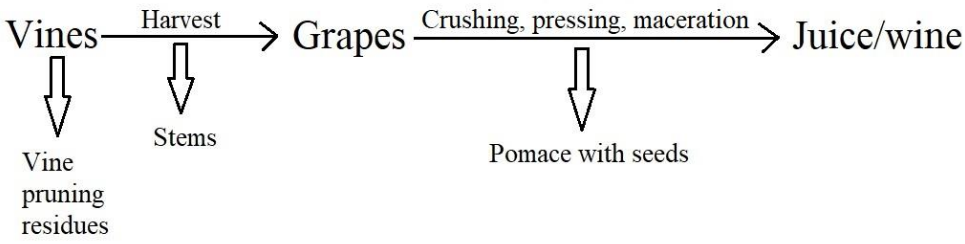

Figure 1. General production process of wine and origins of by-products within. Copyright: Hanna Eriksson.

Figure 1 aims to display where in the production process the by-products are generated. Beyond pomace, vine pruning residues and stems also contribute to the immense volumes. In addition, enormous quantities of water are required throughout the production process, which is already a scarcity in many areas of the world. Understanding that the vast amounts of grapes produced for wine production generates extensive by-products gives rise to questions as to how the by-products are and can be utilized. Not only to add economic value to the production, but in addition to strive towards a more environmentally sustainable industry.

1.2 Purpose and demarcations

The aim of this literature study was to provide a deeper knowledge about the extent of waste in the wine industry. The main plant residue in focus was grape pomace. In addition, to investigate current and previous methods of by-product management, compile them and evaluate the benefits and drawbacks with applying them. An additional aim was to present, compile and evaluate more innovative uses that can be applied to utilize the full potential of the plant residues more efficiently, while adding value to the industry and reducing impact on the environment. Both the previous, current, and potential future applications on different scale wineries was also evaluated. This was made in order to determine if they would be beneficial or detrimental to the production value.

Following questions were intended to be answered:

- How much of the crop is used for the final production and what remains?
- What are the possibilities of utilizing the plant residues?
- How are methods applied and what do they generate?
- What are the outcomes of implementing techniques to reduce waste for the production process?

1.3 Method

In order to execute this literature study, appropriate literature was retrieved from a personal collection and scientific databases such as ScienceDirect, Google Scholar and PubMed through the search engine Primo. Keywords employed to find literature of interest were mainly: “wine”, “waste”, “utilization”, “grapes”, “residue”, and “pomace”, in different combinations. A few review articles were used as a source of suitable references. Statistical data were collected at FAO. To obtain leading-edge, modern findings, publication dates of studies were restricted to after the year of 2000.

2. Current by-product management

2.1 Grappa

Grappa is a type of brandy from Italy with great cultural and economic value. In 2018, Italy produced 85,000 hL pure alcohol equivalents of grappa. It is a distillate made of the grape pomace (GP) leftovers from the wine industry. Portugal and Spain have similar versions named bagaceira and orujo, respectively. The pomace from both red and white grapes are used (Cisneros-Yupanqui et al., 2022). The pomace from white wine production has more pulp and sugar left as the pomace is not fermented with the juice in opposition to red wine production (Mendes et al., 2013).

This is one direction to go to streamline by using residues from the wine industry. Despite this, the extraction products are almost solely alcohol. The pomace still remains although in lower volumes. The loss of polyphenols and bioactivity is marginal. It has even been proposed that the Maillard reaction occurring when distilling GP can lead to an even more bioactive by-product (Cisneros-Yupanqui et al., 2022). The production of grappa and similar alcoholic beverages from GP plays an important role. Not only as a source of tradition and monetary influx but also as a way to enhance availability of the bioactive compounds that reside in the GP.

Currently, the waste from the production of grappa is not treated further to extract the remaining phenols. Additional research on applications for the compounds of interest is necessary in order to create a more sustainable production.

2.2 Landfill

Grapes are harvested during a brief period of time from August to October. This entails the amount of pomace is likewise largely produced during this time. Discarding pomace in landfills has been a widespread practice, even though it has been and still is a non-efficient means of utilization. Grapes contain high levels of phenolic compounds and as a result of this they are not easily degraded. The subsequent unpleasant smell generated can appeal to flies and pests that in turn can spread disease. The phenolic compounds give rise to a lower pH of the GP. The low pH can result in environmental issues including lower quality of ground water, oxygen depletion in the soil, and leakage of nutrients, disrupting the health of enclosing flora and fauna (Dwyer et al., 2014).

To be able to discard the GP in this manner, treatments to render the waste environmentally harmless or even beneficial should be made ahead of the dispensing of the waste. This additive action would reduce the environmental impact of waste disposal but would also be coupled with waste treatment costs for the winery. Currently, this alternative of waste disposal does not add value to the production, no matter the scale of wine production. Large wine producers might have a more beneficial economy to apply waste treatment. However, they are also more likely to damage the surrounding environment and water quality, due to the extensive amount of waste generated. Smaller wine manufacturers might not have the same economic means to take measures to render the waste harmless, but their waste is neither as extensive in amount.

There are directives from the European parliament and of the council that states that waste from food production should be minimized, and that the environmental and human health should be protected. Directive 2018/851 argues that member countries should use economic incentives to motivate waste treatment and recycling, but that some countries might lack the necessary infrastructure. The work to reduce food related waste is thus a long term project (Directive 2018/851 of the European Parliament and of the Council).

2.3 Feed

Grape pomace, or grape marc, is often given to livestock as a feed supplement. The addition of grape marc in feed has been motivated by the ambition that the content of bioactive compounds could improve the overall health status of the animals, and the nutritional content of the products derived from them. Reducing the environmental footprint of animal husbandry have been a further intention, along with using waste from the wine industry resourcefully. Despite good intentions, studies have found that this might be an inefficient way to fully exploit the nutritional potential of this by-product.

It has been proposed that the condensed tannins in GP could decrease the urinary nitrogen excretion in non-lactating dairy cattle. Condensed tannins are a group of polyphenols with antioxidative properties (Ferri et al., 2016). To evaluate the accuracy of this, Greenwood and co-workers randomly divided eighteen cows into two groups with one of them receiving a supplemental 3 kg of grape marc to their regular pasture and feed. After nine days of this diet, the researchers concluded that the cows fed grape marc had unchanged urinary nitrogen excretion and a 22% increase of faecal nitrogen excretion compared to the control group that did not receive grape marc (Greenwood et al., 2012). These findings imply a decreased nitrogen digestibility due to the increased faecal nitrogen excretion. This outcome was not what the researchers hoped for, but it does not necessarily mean it would be fruitless. The manure with higher nitrogen content could be used as fertilizer in organic farming. When observing these findings, it is also important to keep in mind the small-scale of this study. The results might have been different with a larger group of cows or by observing the long-term effects of grape marc addition to their regular diet. It has been suggested that the digestibility of GP could be improved by biologically removing lignin before supplying it to livestock as feed (Nerantzis & Tataridis, 2006).

Another study investigating the condensed tannins' effect on nitrogen partitioning focused on alterations to the composition of proteins in the milk. Here, ten lactating cows were fed either 1.5 kg DM GP or 2 kg DM soybean and beet mix. The trial was conducted during 28 consecutive days. The results discovered that the milk yield, and its content of fat and protein was unchanged in both diets. However, bioactive proteins related to the blood-milk-barrier were found in the milk from the cows fed GP. The presence of these proteins could imply that the blood-milk-barrier was affected by the diet. One plausible explanation to these outcomes could be the altered carbohydrate intake which might influence the milk composition and yield. A second could be other bioactive compounds present in the grape marc, such as anthocyanins that can function as phytoestrogens. Their presence could weaken the blood-milk-barrier and make it more permeable (Scuderi et al., 2019). What could be beneficial with this diet is that by-products are utilized. Assuming the cows would otherwise eat silage, replacing a share of that with GP would free land to grow food for humans rather than feed.

Grape marc contains multiple sources of biologically active compounds, condensed tannins are just one group of them. The amount and composition of bioactive compounds is highly varied between grape varieties, and conditions under which they are grown. Further research is necessary to acquire sufficient knowledge regarding nitrogen metabolism; in particular, to resolve how tannins or other polyphenols present in grape marc can influence and interfere with the mechanism. The bioavailability of the beneficial compounds might also be evaluated to a greater extent in the future. Hydrolysable polyphenols have been found as more bioavailable compared to condensed tannins (Brenes et al., 2008).

The influence of grape pomace concentrate (GPC) on the gut and intestinal bacteria have been investigated in chickens. Inclusion of GPC was found to correlate with a more diverse bacterial flora, when compared to birds not fed GPC and birds with antibiotics included in the feed. The bacteria where *Lactobacillus*, *Enterococcus*, *Escherichia coli* and *Clostridium*. Birds fed with GPC also had longer villi compared to the other two groups. The increased biodiversity of the gut and intestinal bacterial population, and the elongated villi, could indicate that the chickens have a decreased susceptibility to infections and increased absorption ability of nutrients. Phenolic compounds such as resveratrol, quercetin and phenolic acids can inhibit growth of pathogenic microorganisms. Hence, including GPC in the feed might be a potential replacement for the current day use of antibiotics (Viveros et al., 2011).

Brenes et al. found that chickens fed with GPC had increased antioxidant activity in the faeces and breast muscle, with values being the same as with vitamin E supplementation, compared to the control with no supplementation. This suggests that diets including GPC have higher scavenging free radical capacity and can thus inhibit oxidative reactions. Moreover, lipid oxidation in breast muscle tissue was lower in chickens supplemented with GPC, equal to that of vitamin E supplemented chickens. Vitamin E is the most commonly used antioxidant supplemented in feed today. Disadvantages with vitamin E supplementation includes its synthetic origin and the uneven distribution in tissues. GPC in this study served the same function as vitamin E would, and would be a capable substitute as the health of the animal was not compromised (Brenes et al., 2008). Choosing to reuse rather than produce is a wiser option if the outcome is identical.

2.4 Composting

The outlook on wine production is generally that it is environmentally friendly. However, the production of wine is a very resource demanding process that generates not only solid organic waste but also a tremendous amount of wastewater sludge.

Aerobic digestion, or composting, is the degradation of plant matter by microbes. This method utilizes the plant residues by turning it into a material that can be reintroduced to the soil to recycle nutrients, and partially replace externally acquired fertilizer (Burg et al., 2014). During microbial degradation, methane and carbon dioxide is emitted. When this is done in aerobic conditions, for an example in compost piles, the aim is that the greater share of emissions is represented by carbon dioxide. This can be accomplished by frequent turning, to keep the material aerated. If the microbial degradation is done anaerobically, methane is produced to a larger extent (Cáceres et al., 2012). When digesting plant matter aerobically, the production of methane is undesired. Methane is a greenhouse gas, that over a period of 20 years can be 61 times more potent than carbon dioxide. Methane can also be very hazardous and self-ignite where produced (Shine et al., 1990).

Composting is most cost efficient if done on site and preferable over external waste management options. The latter is most often done by companies devoted entirely to waste treatment. Waste on these facilities is most often placed in landfills or incinerated, with production of compost being a less frequent application. The wineries then purchase back a portion of the compost to obtain organic fertilizer. Few data are available on the proportion of wineries which compost their own residues, however, as an example, in the province of San Juan in Argentina only 5% of wineries aerobically digest their solid residues themselves (Cáceres et al., 2012).

When composting, it is important that sanitation is successful before reintroduction to the soil. Sanitation happens as a result of the thermophilic temperatures generated during composting, eliminating crop pathogens. The addition of compost to the soil has been proven to suppress plant infections. Composting is most often done by combining two or more materials. It has been found that composting stalks and sludge together generate compost with desired properties as a soil improver. They include satisfactory water holding capacity, high level of porosity and no sugars, acids or ethanol remaining post-compost (Ruggieri et al., 2009). Even though composting is possible without any advanced technology, optimization leads to a less labour-intensive process. It will also generate a more dependable, high-quality product.

There are many benefits with wineries investing in equipment to become self-sufficient in waste treatment. Firstly, the investment is likely to pay back within five years, writes Ruggieri and co-workers. This is due to reduced expenditure on external waste management and fertilizer. Secondly, reduced environmental impact as waste and fertilizer will be transported shorter distances. Thirdly, marketing that the winery manages its own waste can be socially beneficial and improve the customers' outlook on the winery and its produce. This can in turn lead to increased demand and revenues (Ruggieri et al., 2009).

Composting GP alone presents challenges, due to the low pH. The microbes involved in composting prefers a pH closer to neutral, which is why a combination of plant residues is a necessity. This might pose as an obstacle for farms that exclusively grows grapes for wine production (Burg et al., 2014).

An experiment was made on three compost piles to investigate how fast they increased in temperature. Increasing temperature is important to ensure sanitation. The piles consisted of different ratios of GP, vegetable waste, wood chips and livestock manure. The GP share was 31-48% of the total. They found that the pile with 43% GP increased in temperature more slowly initially, but finally all piles reached a temperature above 45℃ for minimum 5 days, which was the requirement (Burg et al., 2014). Furthermore, frequent turning was found to speed up the decomposition, which might argue machinery is crucial for in-house waste management.

2.5 Incineration

A fast alternative of waste removal often selected is open air burning, an option that brings undesirable drawbacks. These are comprised of, but not limited to, loss of air quality, risk of the fire spreading and carbon dioxide emissions. Burning can also release small airborne particles and persistent organic pollutants that can be hazardous for human, animal, and environmental health. The pollutants are not static in the atmosphere but can migrate all over the globe post-release. Legislation is working towards winding up open air burning, and the method is prohibited or limited, for an example in Italy since 2010 (Giorio et al., 2019).

Controlled burning is a much better alternative, but the moisture in the organic waste can make the process difficult. The location where burning takes place can also face opposition from the public. To decrease demand for firewood for thermal energy, vineyard pruning residues (VPR) could be a better option. The environmental impact of burning VPR was evaluated in a study by Giorio and co-workers. They found that the amount of emissions of macropollutants were below set limits, but the micropollutants make this a non-option for households. They included among others polychlorinated biphenyls and polychlorinated dibenzodioxins, as a result of the use of chlorinated pesticides in viticulture. Incineration should be done solely on facilities with appropriate filters installed. The high content of copper in the ash can make this waste unfit for reintroduction to the soil, and might have to be discarded as waste (Giorio et al., 2019).

3. Innovative ideas under establishment

3.1 Construction

Grape pomace is rich in lignocellulose, in varying degree depending on the grape variety. Muñoz et al. conducted a study in 2014 where they used GP as an additive to the clay used to construct bricks. This was performed to investigate if the addition of GP would improve the thermal insulation of the bricks.

They found that the bricks with GP had increased porosity, increased water absorption and were more brittle compared to bricks without GP, implying these bricks should be used for construction in areas with less rainfall and without harsh conditions. Nevertheless, the bricks with GP were lighter and less water was acquired to assemble the paste, meaning costs for logistics and production could be lower. Finally, they found that thermal conductivity was reduced, and thermal transmittance was improved by 10%, meaning the bricks does not improve thermal insulation (Muñoz et al., 2014). Using GP in this manner could be a suitable alternative if the future was not predicted to endure even more extreme weather than there currently is.

A similar material was constructed using vineyard pruning residues. This material with comparable properties to the initially mentioned was found to comply with European regulations. It should also be mentioned that these by-products are generated in larger quantities at higher speed compared to forests in agreeable climates (Nerantzis & Tataridis, 2006).

3.2 Nutraceuticals

The bioactive compounds in GP have been proved multiple times over to possess antimicrobial and anti-inflammatory properties. Thus, extraction of these compounds could add value to the production as nutraceuticals. Nutraceuticals, or functional food, refers to foods with positive effects on health (Carpenter et al., 2007). The phenols in GP have provided evidence to lower the risk of developing chronic diseases, such as cancer and neurodegeneration (Del Rio et al., 2013). The antioxidants have been found to inhibit saturated fats from accumulating in the blood vessels. This leads to a decreased risk of coronary heart disease linked to the intake of foods rich in this type of fats (Nerantzis & Tataridis, 2006).

What is important to bear in mind is that the activity of the polyphenolic compounds varies with extraction method. In addition, when the compounds are ingested, their chemical form is degraded and shifts, and low concentrations of the initial compounds are found in the blood stream (Ferri et al., 2016).

Ferri and co-workers recovered polyphenols from red GP, both wet (WP) and dry (DP). Their aim was to determine the antioxidant and anti-cholesterol activity of the polyphenols. To recover polyphenols, they used enzyme-based digestion and ethanol extraction.

Firstly, they added 0.5, 1 and 2% of different enzymes to both WP and DP and incubated the GP for 2-24 hours. The temperatures were adjusted with respect to each enzyme.

In this initial step, they found that WP had a much greater number of extracted polyphenols compared to DP. Drying pomace seemingly decreases the number of extractable polyphenols. WP had the greatest quantity after 2 hours, where DP quantities where similar independent of duration and the highest values at 24 hours. Enzyme treatment for longer than 24 hours resulted in a lower yield in both WP and DP, likely as a result of metabolite degradation. Combining two or more enzymes did not increase yield.

After treating the pomaces with enzymes, the coloured supernatant was incubated with 95% ethanol overnight at 24℃. Both the aqueous and alcoholic phase were subjected to spectrophotometric analyses. In the last step, they found that ethanolic extraction was significantly more effective at improving the extraction of polyphenols, with almost 3 times higher levels compared to the water phase. This could be because of saturation or more rapid anthocyanin degradation in the aqueous medium. Earlier studies using different cultivars had reached higher levels of polyphenols, reminding us that the content varies between grape varieties and growing conditions. The researchers found that pre-treatment of the GP was of importance. The crystalline structure of starch in the cell walls, lignin and low molecular weight phenols forming covalent bonds with residual sugars can hinder enzymes. Despite this, higher levels of polyphenols were found in the enzyme treated samples than in the controls. When determining antioxidant activity, the highest activities were measured in the samples with high concentrations. The WP was twice as active as the DP.

In regard to the ability of the samples to inhibit cholesterol, they found that the control aqueous extract up-regulated the activity of a gene connected to uptake of cholesterol. They investigated two genes involved in the mechanism, with only this specific sample inducing change in one of them. They also found that the induction was concentration dependent. The results from this study were supported by previous findings of supplementation lowering LDL-cholesterol and increasing HDL-cholesterol levels (Ferri et al., 2016).

The extraction of polyphenols shows great promise as a mean to improve the health of the general population of the world. Further establishing which polyphenols have the greatest positive impact and optimal concentration could present this addition as a method to counteract the growing issues with coronary heart disease. Depending on the rate of degradation and temperature range, they could be used in extruded foods, cereals, and bars. The content could be adjusted to a daily recommended intake for the best possible effect.

3.3 Food additives

As previously mentioned, GP has a high content of antioxidants (Ferri et al., 2016). These compounds have generated great interest for application in the food industry, as additives to reduce lipid oxidation in meats rich in saturated fats. To investigate the inhibiting properties on lipid oxidation of grape seed extract (GSE) in meats, Carpenter et al. measured lipid oxidation (TBARS) in raw pork patties stored for up to 12 days in 4℃. The raw pork patties were packaged in modified atmosphere packs with 75% O_2 and 25% CO_2. Moreover, they measured antioxidant activity in cooked pork patties to determine the thermal stability of GSE and made sensory evaluations to ensure flavour, texture and appearance was not impacted negatively by the addition.

The results showed a significant decrease in lipid oxidation in the raw pork patties with GSE compared to the controls, even after 12 days. The decrease of lipid oxidation was greater with increasing concentration of GSE. Increasing concentrations of GSE also reduced the lipid oxidation in cooked pork patties, implying thermal stability of the addition. The sensory properties were unaffected by the addition except a minor increase in red colour of the meat. The redness most probably stems from the red colour of GSE itself and was not perceived negatively by the sensory panel (Carpenter et al., 2007).

Using GSE as a food additive to prevent lipid oxidation in meats is a good application, with rancidity of meats being highly undesirable for both producers and consumers. The inhibition of lipid oxidation is difficult to assign to a specific compound as GSE contains multiple compounds with antioxidative properties, and the effect might be synergistic. Nevertheless, GSE has proven to be a natural additive that prolongs shelf-life and in addition supplies meat with a desirable colour. Also, the proanthocyanidins in GSE have been proven to display antimicrobial properties against different pathogens. The flavonoids quercetin and naringenin especially has previously been reported as antimicrobial compounds. Inhibition of growth has so far been found for *S. aureus, P. aeruginosa*, *Klebsiella* spp. and *E. coli* among other pathogenic bacteria (Mayer et al., 2008). Many of these bacteria are associated with food products of animal descent, further motivating the use of GSE as a food additive to prevent spoilage and outbreaks of foodborne disease.

3.4 Adsorbent

The vineyard pruning residues and parts of the crop remaining after harvesting of the grapes is in short known as bagasse. This abundant and cheap natural material could be useful in ways we have not previously anticipated. Clean water for an example is often taken for granted in wealthier countries such as Sweden but is in fact a costly operation to supply. Rather than producing filters or treatments for removal of heavy metals, use of a by-product that would otherwise be destined for incineration could be a better alternative. The potential of grape bagasse as an adsorbent of heavy metals could function as an equally efficient option, with lower cost and environmental impact.

The adsorption ability of grape bagasse was investigated in a study conducted by Farinella and co-workers. They used glass columns packed with grape bagasse and used a pump to pass through solutions containing cadmium or lead respectively. The concentrations were 0.5-600 mg per litre for cadmium and 5-600 mg per litre for lead. They also did a competitive mix with 100 mg of each metal per litre. The pH values of the effluents were adjusted by the use of NaOH.

Findings displayed the importance of pH for binding capacity. Absorption of lead was more efficient at lower pH values and that of cadmium at higher pH values. The time to reach equilibrium was five minutes, which is acceptable. Multiple filtrations might be needed depending on the initial concentration of heavy metals to achieve values acceptable for consumption. In the mixed solution, adsorption of lead was favoured. When lead bound to the grape bagasse, cadmium was released, indicating a stronger affinity for lead (Farinella et al., 2008).

This is an innovative way to use by-products from the wine industry, but further testing is acquired for safe application on large scale water treatment centres. There are already abundances of natural materials that can be used for effluent treatments, such as clay, coal, and rice husks (Farinella et al., 2008). Finding a method that does not generate further waste would be preferred. The used grape bagasse will be contaminated and unfit for usage in a sequential step without an intermittent step designated for removal of the heavy metals.

3.5 Biofuel

Due to the high levels of lignocellulose, grape pomace is a suitable candidate for the production of bioethanol. Few studies on bioethanol production from GP have been conducted, but they have been made with similar plant materials such as apple pomace (Hernández et al., 2021).

The production of bioethanol from apple pomace was initiated by milling and pressing the pomace. The liquid and solid phase were separated. The liquid phase was first hydrolysed by acid, to digest complex structures and make them more easily available for the yeasts. It was then anaerobically fermented for 0-200 hours at 25-35℃, with added *Saccharomyces cerevisiae* in concentrations ranging from 0.02-0.2 g/L. The solid phase can be used for composting.

Following fermentation, the samples were distilled. From the distillation, vinasse was created as a by-product. If untreated vinasse is released into nature, it can cause similar issues as pomace discarded in landfill. However, it has been used with great success as fertilized irrigation, and to increase speed of decomposition during composting. The mechanism is not known but vinasse has been found to enhance microbial activity (Hernández et al., 2021).

The researchers found that 144 hours of fermentation yielded the greatest cell growth. When the pomace was fermented for that time, at 30℃, and with 0.1 g/L of added yeast, 99.3% of the carbohydrates in the pomace liquid were consumed. 6.85% of bioethanol with 99.5% purity was produced during previously mentioned conditions. Moreover, the researchers believed that the proportion of ethanol produced could be increased by replacing the acid hydrolysis with enzymatic hydrolysis as a preparatory step (Hernández et al., 2021).

The low pH of grape pomace could hinder the production of bioethanol. A possibility could be adjusting it using OH^- to create more optimal conditions for fermentation. Beyond using bioethanol for fuel it is commonly used in cosmetics and pharmaceutics (Chowdhary et al., 2021).

A second option for biofuel production was previously touched upon; methane produced during fermentation. When producing wine, being able to keep temperatures stable is a priority, making all wineries independent of scale vulnerable to fluctuations in price and availability of commercial electricity. A reduction of the dependence on externally sourced electricity can be achieved by anaerobic fermentation. On-site fermentation under controlled settings in sealed tanks with an outlet for the gas to flow through can be coupled with a microturbine, to reduce the previously mentioned dependence. The energy yield from the microturbines can range between 25-300 kW. It has been proposed that each tonne of GP can produce roughly 31 kWh. The production of wine that generates that tonne of GP would require about 69 kWh, meaning almost half of the energy demand can be covered by the production of biogas (Cáceres et al., 2012).

In Sweden, there are currently incentives for producing biogas from manure. The payment for farmers can be up to 0.4 SEK for each kWh produced (Jordbruksverket, 2022). The incentive is meant to cover the costs that arise when producing biogas. Hopefully initiatives of this kind are or will be adopted by more countries ahead.

Many advantages seem to come from producing biogas. Beyond covering part of the costs for electricity, a high-quality soil improver is simultaneously produced. When reintroducing the degraded plant matter to the soil where new vines are grown, nutrients are returned, the humus improved, and the carbon cycle closed. No GP is left behind and rather than paying for the removal, the wineries can gain from it in more ways than one. In addition, the wineries satisfying part of their own energy requirement by producing their own electricity from a renewable source is a far better option compared with using fossil fuels for that same purpose.

4. Discussion and conclusion

Historically in rural areas, no by-products were considered to be waste. Periods that generated low yield taught the farmers to make use of everything that came of the crop. But with increasingly large, monocultural, one-directional vineyards, this lesson was left behind. Only one directive seems to remain; to produce high quality produce at low cost and high speed. By-products from the wine industry can serve many purposes and provide additional income to the wine producers. Despite this, since the agricultural industrialization, the most common practices appear to have been incineration and landfill. The generated by-products have been seen as without value and as waste to be disposed of in one way or another.

What now makes wine producers request that researchers investigate options for closing the carbon cycle and finding alternative applications for the by-products generated is mostly a response to increased environmental regulations and legislation. The consumers are also more aware of the ongoing climate change and that the issue with waste needs to be resolved (Nerantzis & Tataridis, 2006). The motivation of the wine producers to apply new innovations is largely dependent on the extent of the economic gain and the availability of the technique. Further increasing costs of waste management also serves as an incentive to produce additional products from what was previously considered to be waste. The revenues from these products along with the decreased volumes of waste will aid in reducing these costs.

What should be and probably is the most pressing motivator to re-evaluate current methods of waste removal is the raised awareness of the vulnerability of nature. Governments have acted on this by setting higher demands on the industries that generate waste that can be harmful for the environment, animals and humans. The industries in turn, will have to find alternative methods to meet these demands. Using methods that fulfil only the purpose of removal cannot continue to be applied. Rather, alternatives that recycle nutrients or energy should be a given. There are endless possibilities for the by-products of wine production, and that outlook needs to be adopted to a much higher degree.

One obstacle to the utilization of the by-products could be the extensive use of pesticides on vines. Vines are highly susceptible to various plant pathogens, like the moulds *Botrytis cinerea*, *Plasmopara viticola* and *Uncinula necator*. There are also insects that significantly reduces the yield of grapes, such as *Lobesia botrana*, or grape moth. The heavy use of pesticides has resulted in pesticide residues being found in the grapes post-harvest, even in grapes claiming to be organically farmed (Schusterova et al., 2021). If the pesticides are chlorinated the continuous use of the by-products could be harmful for the environment. How these compounds behave, and their stability should be further researched, to determine their durability. If pesticides were to remain in for an example compost, this could lead to higher levels of pesticides than intended in the fields. In the long run additional consequences could be resistance to pesticides in fungi, weeds and insects, further complicating the cultivation of grapes. Thus, the practice of viticulture leaves room for improvement.

A circularity in the by-product treatments could be a first step to shifting focus from the main produce that is wine. The grapes could be centred, and what can be drawn from them the side streams, with wine being one of them. In Figure 2, this method has been attempted to be explained.

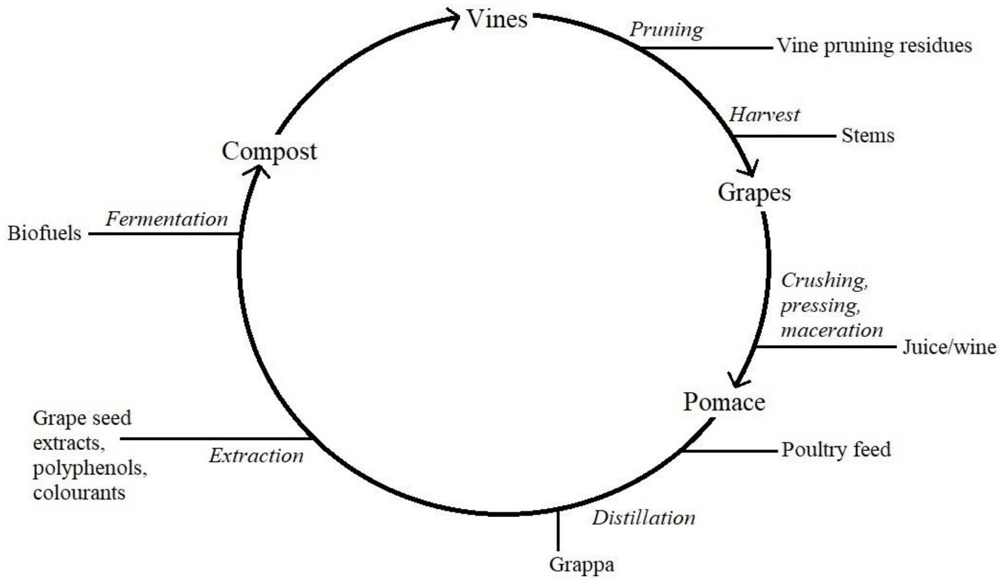

Figure 2. A circular method to utilize the by-products from wine production. Copyright: Hanna Eriksson.

This way, no by-products are without purpose. The vine pruning residues and stems could re-enter the cycle in the fermentation stage or be used in construction. A part of the pomace could be ensiled to be used for poultry feed. The distillation step for production of grappa could be optional, although it could enhance bioactivity of target compounds for the following step. Extraction could be beneficial not only to add value but also to remove compounds that could inhibit fermentation, when used in later steps. The pH could be raised by the process and hydrolysis would make the nutrients more accessible for the microbes involved in the consecutive steps. Both bioethanol production (fermentation of sugar-containing residues) and biogas production (anaerobic fermentation) could be introduced as separate or consecutive steps. The biofuels can be either sold or used for the energy demands of the farm. Both alternatives would result in an economic gain for the individual wine producer. The secondary by-product vinasse could be used for fertilized irrigation and reduce the demand for commercially bought fertilizer. The final product in the loop would be compost, which could be reintroduced in the soil to improve the humus of the soil and to return nutrients. The steps in the circle could be adjusted to the individual ambitions of each winery. Including the extraction step could be limited to red GP, as they are expected to contain greater amounts of bioactive compounds, as indicated by their strong pigments. The production of bioethanol could be restricted to white GP, as white grapes used toward production of white wine are removed from the juice and not fermented with it. This will make the white GP contain higher levels of residual sugars and be prone to increase the yield of bioethanol.

Knowing ahead the alternatives that exist for by-product management makes handling by-products significantly easier. If a winery wants to extract bioactive compounds and pigments, or produce GSE, the requirement to dry and store GP will be reduced. Pomace that would go to poultry feed would be transported to a facility to be ensiled, whereas GP for previously mentioned applications would be better used instantly, still wet. External companies interested in extracting the bioactive compounds for application in cosmetics, nutraceuticals or pharmaceuticals could come to an agreement with the wineries for transportation and payment. Planning the route for side streams and collaboration between wineries and external actors would simplify the process of utilization.

Wineries producing less than 50 tonnes of GP have been found to gain economically from composting, so a composting or anaerobic fermentation step as the final one in the loop can be applied on all wineries independent of size (Zhang et al., 2017). Perhaps if the production is unusually small, the winery can collaborate with a larger winery in close proximity and donate their GP to them. This could be the case if the production of wine generates small revenues that makes investing in optimizing equipment for composting unattainable. Nevertheless, most wineries will benefit from composting from an economic viewpoint. Investing in technology to harvest the biogas to cover half of the energy required for processing grapes can be done simultaneously. If the economy of the winery allows for the investments, the investments would pay back long-term (Ruggieri et al., 2009).

To conclude, the interest to reduce the environmental impact of the by-products generated during the production of wine is increasing. Multiple alternatives are accessible for management of what remains of the crop after production of wine on wineries of all sizes. The alternatives show great promise as new materials for construction, active ingredients in feed, foods and pharmaceuticals, fuel, energy, and soil improvement. The outcome of implementing new techniques is reduced dependency and expenditure on externally sourced input, whether that is commercially bought fertilizer, electricity, or fuel. Leaving nothing behind of the initial plant eliminates external waste management costs, reduces the environmental impact of the production process, and contributes to making the wine producing operation sustainable.

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Appendix I

8.98 l pure alcohol in total per person and year*0.423 wine share = 3.8 l pure alcohol per person and year from wine
Estimated 8% alcohol means one glass with 150 ml of wine contains 12 grams pure alcohol
12 g/150=0.08
12*5=60 g pure alcohol per bottle (750 ml)
3800 ml pure alcohol per person and year from wine/60 g pure alcohol per bottle = 63.3 bottles of wine per person and year
250 g grape pomace per bottle*63=15750 g grape pomace per person and year

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