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ADVANCES IN GRAPE MARC COMPOSTING: A REVIEW

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Abstract

During the winemaking process, large amounts of waste are produced, including pomace, skin, stalk, wastewater, less and shoots, which contribute significantly to environmental degradation. Grape marc, which accounts for 25% of grape weight and is left over after juice extraction, can be used in a circular approach for green energy, component extraction, energy recovery and a variety of applications such as fuel, alcohol, biosurfactants and composting for natural fertiliser. There are numerous techniques for obtaining a final compost, including static systems (aerated static piles, continuous vertical reactors and in-vessel tunnels) and turned or agitated systems (turned windrow, agitated bed and rotating drum). Enhancing compost value involves co-composting the grape marc with organic byproducts like manures, olive oil industry waste, coffee grounds and more. Vermicomposting, that can be applied indoors and outdoors, yields nutrient-rich organic material for crops efficiently. This method offers advantages such as year-round composting and quicker production of superior-quality nutrients.

Key words: *grape marc, co-composting, vermicomposting*

INTRODUCTION

Waste and wastewater are produced in large quantities during the winemaking process. Before they can go back into the environment, these residues need to be recycled or treated. The winery waste chemical composition is affected by the conditions and moment of the harvest. Harvest and post-harvest are the two distinct times that are usually taken into consideration in the winemaking process. Compared to the post-harvest period, the amount of solid waste and wastewater generated during harvest is significantly higher (Oliveira & Duarte, 2016). Among the main waste products from the winery are grape marc (or pomace), skin and stalk. In addition to these waste products, a significant amount of waste, including water, lees, shoots and some filtration residue produced by wineries, is another major factor contributing to environmental degradation (Ahmad et al., 2020; Musee et al., 2007).

The wastewater from wineries is created during processing and cleaning procedures, such as washing grapes during crushing and pressing, rinsing fermentation tanks, filtration, cleaning barrels, bottling and aging (Flores et al., 2023; Andreottola et al., 2009; Musee et al., 2006). Significant wastewater flows are produced during the grape-processing phase (vintage and racking) and considerable amounts of water are used in the months that follow, as bottling and container cleaning are nearly constant activities (Bolognesi et al., 2020; Masi et al., 2015). The wine industry is one of the industries which uses high amounts of water; taking into account all of the operations that were previously mentioned, a wastewater/wine ratio of 14 L/0.5 L was reported (Bolognesi et al., 2020; Oliveira & Duarte, 2010), with an average value of 4 L wastewater/1 L of wine (Flores et al., 2023). The wastewater from wineries is acidic (with a pH less than 5.5), phytotoxic and contains salts, organic matter, trace elements like magnesium, calcium and sodium. It also has a high level of biological oxygen demand, a significant amount of sugars, organic acids, glycerol and alcohols, as well as a microbial population of yeasts and bacteria (Bharathiraja et al., 2020; Lucas et al., 2009; Vlyssides et al., 2005).

The vine shoots are agricultural byproducts of vine pruning, with a global production of 15 million tonnes each year. Typically, they are burned to stop phytopathogen growth or ground and left in the field as an organic fertiliser (David et al., 2020). They are made up of cellulose, hemicellulose and lignin and may be utilised to create a variety of biobased products including proteins, bioactive compounds, biofuels like as ethanol and biogas (Baptista et al., 2023; Pachón et al., 2020; Jesus et al., 2017; Pérez-Rodríguez et al., 2016), oligosaccharides (Dávila et al., 2016), proteins, polyphenols (Rajha et al., 2014), lactic acid (Garita-Cambronero et al., 2021), xylitol (Rivas et al., 2007) and biosurfactants (Cortés-Camargo et al., 2016).

The grape marc or pomace is composed of grape skins, seeds and stalks, as well as the distrupted cells from the grape pulp (Crespo-López et al., 2022; Perra et al., 2022; Gómez-Brandón et al., 2019), which represents approximately 25% of the total grape weight used in the process (Salgado et al., 2019). It is the waste that remains after the juice from grape pressing is collected for wine production and it is made up of polyphenols, pectic polysaccharides, heteroxylans, cellulose, alcohol, unfermented sugars, tannins, pigments and other valuable products (Pinter et al., 2019; Corbin et al., 2015). It has been estimated that the production of 6 L of wine generates approximately 1 kg of grape marc, accounting for an annual global production of 10.5-13.1 Mtons of grape marc (Gómez-Brandón et al., 2019). The quantity and quality of grape marc will vary depending on the size of the winery and the winemaking methods used (Muhlack et al., 2018). According to Frîncu et al. (2019), when researching the feed properties of winemaking byproducts, standardised analysis methods such as dry matter, crude protein, aminoacids, crude fat, fatty acids, crude fibre, ash, calcium, copper, iron, manganese and zinc, phosphorus, gross energy, polyphenols concentration and antioxidant capacity are typically recommended. Grape marc, as an organic product high in lignocellulosic compounds, can be used in a circular approach as an attractive feedstock for green energy production, extraction for useful components, thermochemical and biological treatments for energy recovery, fuel or beverage alcohol production, biosurfactants production, as well as in composting to obtain natural fertiliser (Muhlack et al., 2018).

Composting is a biological process that turns organic wastes into a homogenous, plant-available material in an environmentally friendly way under aerobic conditions with suitable temperature and moisture. In the presence of oxygen, nitrogen and carbon, a variety of microorganisms carry out complex metabolic processes to create their own microbial biomass throughout the composting process. Additionally, the microorganisms produce heat and compost (a solid substrate that has less carbon and nitrogen but is more stable) during this process (Meena et al., 2021). There are mainly four stages to the composting process: a mesophilic initial phase, during which simple compounds like sugars or amino acids are broken down by mesophilic bacteria and fungi by quickly raising the temperature; a thermophilic second phase, during which thermophilic microorganisms break down organic matter (fats, cellulose, hemicellulose and lignin). The reduction in the feedstock's organic carbon content during this phase is attributed to the metabolic activities of heat-tolerant microorganisms. Finally, a lowered temperature and diminished microbial activity are the hallmarks of the cooling phase. Within this, mesophilic microorganisms recolonize the compost pile and break down the remaining sugars, cellulose and hemicellulose, to produce compounds that resemble humic substances. After this, the maturation phase occurs, during which the rate of organic matter decomposition decreases and the rates of organic compound polymerization and humification increase. (Rastogi et al., 2020; Albrecht et al., 2010).

The compost quality is determined by the raw materials used to create a stabilised end result of the biological aerobic transformation of organic matter till the humification process, which is evaluated at the maturity phase. The compost is defined by two characteristics: stability and maturity. The stability correlates to the change of an initially unstable organic matter into a stable organic matter at the completion of composting. The maturity refers to safe use as a result of the absence of phytotoxic compounds (Salgado et al., 2019; Bazrafshan et al., 2016; Martínez et al., 2016; Wichuk and McCartney, 2010).

APPROACHES OF GRAPE MARC COMPOSTING

When talking about grape marc composting, two main approaches are taken into account: the static systems and the turned/agitated systems. Their characteristics and specificities will be described below.

Static systems

Aerated static pile

Aerated static pile composting removes the necessity to turn the compost pile by introducing airflow into the piles (Abdoli et al., 2019). The aeration system in aerated static pile composting technology is made up of a system of perforated pipes connected to timer-controlled blowers. The blowers provide direct process control, maintaining an oxygen level of 5-15% without turning the pile. The piles are frequently topped with a layer of matured compost to avoid heat loss from the upper layers and to provide smell management. The active composting period can be completed in three to five weeks if the pile is properly formed and enough air is supplied (Makan & Fadili, 2020).

Continuous vertical reactors

In this method, the materials are typically loaded through the reactor's top and discharged through its bottom. The composting mass is oxygenated by forcing air up from the bottom. These reactors can handle massive quantities of material (up to 2000 cubic metres) and can reach heights of nine metres. However, height is extremely important, and masses greater than three metres cause serious ventilation problems (Dominguez et al., 1997). Temperatures and other variables can be tracked via ports installed along the vertical wall. Because air warms up as it passes through the composting mixture, the control over moisture is limited. When the heated air reaches the cool mass of new material, it condenses at the top. The composting process takes about 14 days (Arvanitoyannis et al., 2006).

In-vessel tunnels

According to Diaz et al. (2007), in-vessel tunnels are rectangular containers that have typical dimensions of 4-5 m long, 3-4 m high and up to 30 m long. They have dedicated doors for the loading and unloading of materials and are constructed of brick, concrete or metal. Every day, the material for composting is loaded through the loading door. A hydraulic piston is then used to push the feedstock in the direction of the door on the other side. The majority of tunnel designs come with sensors for measuring oxygen and moisture content. Compressors are frequently used to supply air to the feedstock. A computer is used to oversee the entire procedure (Makan & Fadili, 2020; Noble & Gaze, 1997).

Turned or agitated systems

The composting materials in turned (agitated) systems are regularly combined, agitated or "turned" at frequencies that can vary from daily to every two months. As a result, compounds are homogenised by dispersing moisture, transporting materials from the oxygen-poor inside to the oxygen-rich outside and mixing high and low temperature elements. Some compost turning methods may assist to decrease the particle size and rebuild a windrow or pile. Turning is the process of lifting composting feedstocks into the air, mixing them and allowing them to fall back to the ground. Front-end loaders, augers, dedicated turning machines and other equipment may be used (Michel et al., 2022). Turning compost piles raises temperatures due to aeration, which is beneficial during composting (Mulidzi, 2021).

Turned windrow

Turned windrow composting is the oldest and most basic composting technology and it is widely used for stabilising and converting organic substrates to usable and value-added products. Turning windrow composting requires specialised equipment on a regular basis. Diffusion and convection naturally ventilate the elongated piles known as windrows. Despite its simplicity, this technology has significant limitations that should be highlighted, including high labour costs, long lead times and the use of valuable land space (Makan & Fadili, 2020). The turned windrow composting method has benefits such as the possibility to handle a huge volume of material, it is simple to implement and use, involves minimal capital expenses, needs the least amount of infrastructure and equipment, is easily flexible to accommodate demand, enabling small to large-scale operations, is simple to begin and finish and produces high-quality compost (Vigneswaran et al., 2016).

Agitated bed

Agitated bed is a horizontal composting system. It consists of an aerated bed contained within a horizontal bin. The sludge introduced into the bin can be mechanically turned up on a regular basis and removed after 21 days. Curing then occurs outside the bins in an open or covered area (Arvanitoyannis et al., 2006).

Rotating drum

The rotating drum incorporates a tilted rotating cylinder that allows for downward material displacement. A drum's typical dimensions are 45 m long and 2-4 m in diameter. The rotational speed is approximately 0.2-2 rpm. Some drums have internal vanes that, when combined with the rotating action of the drum, force the material towards the exit and contribute to size reduction and feedstock mixing. Moisture and oxygen concentrations in the reactor are monitored and kept at or near optimal levels. This type of reactor is typically used for the active phase of composting, and the composting process can be accelerated by carefully controlling the oxygen and moisture contents (Diaz et al., 2007). The final product that is produced is therefore uniform and consistent and free of any problems related to leachate or odour (Makan & Fadili, 2020).

ADDED VALUE BROUGHT BY DIFFERENT WASTES DURING GRAPE MARC COMPOSTING

Co-composting winery wastes with other organic materials may help neutralise the acidity associated with grape marc, thereby improving the dynamics of the process of composting along with the overall quality of the final product (Gómez-Brandón et al., 2019). Table 1 shows the various organic matter that can be added to the grape marc (pomace) composting process in order to improve the final compost quality.

Table 1. Co-composting winery wastes with other organic matter to improve compost quality

Mixture	**Reference**
Grape marc + Grape stalks	Pinto et al., 2023
Grape marc + Animal manure	Eon et al., 2023
Grape marc + Coffee grounds	Karapantzou et al., 2023
Grape mill waste + Olive mill waste	Chrysargyris et al., 2023
Grape marc + Sugarbeet Vinasse	Díaz et al., 2002
Grape marc + Organic fraction of municipal solid waste	Hungría et al., 2017
Grape marc + Mature vermicompost	Gómez-Brandón et al., 2023
Grape marc + Goat manure + Leaves from garden raking + Alfalfa	Pinter et al., 2019
Grape pomace + Pig manure + Biochar + Fe_2O_3	Zhang et al., 2023
Grape pomace + Goat and Horse manure	Salgado et al., 2019
Grape pomace + Corn straw + Pig manure	Xu et al., 2022
Grape pomace + Wheat straw + Swine manure	Ivanović et al., 2022
Grape marc + Hose leaves + Sheep manure	Barros et al., 2021
Exhausted grape pomace + Cattle manure or Poultry manure	Bustamante et al., 2008
Grape marc + Goat manure + Leaves from garden raking + Alfalfa	Pinter et al., 2019
Grape marc + Sewage sludge + Pelletized wheat straw	Dume et al., 2023
Grape marc + Green herbaceous crop residues + Pruning residues	Alfonzo et al., 2022
Grape marc + Grass clippings + Orange fruit waste	Coelho et al., 2021
Grape marc + Olive mill wastewater + Green waste	Majbar et al., 2017
Grape marc compost + Perlite + Soil + Pumice	Tassoula et al., 2021
Grape marc + Green waste + Straw + Soil + Biochar	Kessler et al., 2021
Grape marc + Waste from orange juice / Waste from tomato soup production / Cattle manure / Sheep manure	Pérez-Murcia et al., 2021
Substrate mixed with Grape marc + Pumice + Pure sphagnum peat + Soil	Paraskevopoulou et al., 2021
Winery wastewater sludge + Grape stalks + Biochar	Pinto et al., 2021
Grape skin + Stalks + Vineyard pruning waste + Zeolite	Cataldo et al., 2023
Green waste + Sugarcane bagasse + Exhausted grape marc	Zhang & Sun, 2016

Co-composting grape marc with residues from olive oil production can provide numerous benefits to the final compost. Blending grape marc with olive oil wastewater to create compost may be a useful fertiliser for lawns. Research by Paplomatas et al. (2004) shows that this mixture can inhibit the growth of *Rhizoctonia solani*, the agent that causes brown patch disease in two types of lawns: *Festuca arundinacea* 'Tomahawk' and *Lolum perenne* 'Applaud'. Furthermore, composts made with wastes from olive mills have several advantageous agronomic traits: low phytotoxicity and the potential to suppress soil-borne illnesses; and these can be used as soil amendments and can effectively replace a portion of the peat moss used in growing media without adversely affecting crop yields (Aviani et al., 2010). Majbar et al. (2018) investigated the compost produced by co-composting grape marc and olive mill wastes. According to the authors, the co-composting process progressed well, with biodegradation of organic matter and bioconversion of unstable matter into a mature, stable product rich in nutrients, with no phytotoxic effect. Also, physicochemical analysis revealed that these composts are of high quality, high in nutrients, particularly N, P, K, Ca, Mg and Fe (Majbar et al., 2018).

The spent coffee grounds and grape marc contain high levels of polyphenols, tannins, cellulose and hemicellulose, consequently laccases and peroxidases are more active in the composts made from them (Sanchez-Hernandez & Domínguez, 2017). As a result, the compost produced by co-composting grape marc and used coffee grounds could be used in the bioremediation of polluted soils (Gómez-Brandón et al., 2019).

Zhang et al. (2023) claim that co-composting wine grape marc, which has a high phenol content, with pig manure can enhance the pig manure's composting process and increase its conversion to humic acid. Another study (Xu et al., 2022) showed that by promoting advantageous interactions between microorganisms, the grape marc effectively extended the thermophilic period and enhanced humification production and compost maturity in the co-composting process with pig manure. The authors believe that using 40% grape marc in the composting mix was the best way to conserve nitrogen, with a 95% germination index as a result. Additionally, Ivanovi et al. (2022) suggests that 40% grape marc is the optimal amount when swine manure and wheat straw are used as co-substrates. Salgado et al. (2019) investigated the grape marc co-composting process with goat and horse manure. They noticed that the compost made from grape pomace and goat or horse manure could be used as organic fertilisers or amendments because it had been proved safe in terms of human pathogens, faecal indicators and phytotoxicity (with more than 90% germination rate in all the treatments). Pérez-Murcia et al. (2021) examined the effects of applying different composts (one made with exhausted grape marc and cattle manure, another with exhausted grape marc and sheep manure) over two different varieties of almonds over the course of a two-year experiment. The results of this study demonstrated that these composts enhanced the biotic activity and nutrient content of the soil, while having minimal effects on the nitrate and salinity levels.

Hungría et al. (2017) studied the co-composting of grape marc and the organic fraction of municipal solid waste (OFMSW) in a 50:50 w/w ratio. They used a pilot scale dynamic respirometer that was operated under aerobic conditions and monitored physico-chemical, respirometric and olfactometric parameters. It has been discovered that combining grape marc with OFMSW neutralises the acidity of grape marc while creating a final composted product that is high in phosphorus and nitrogen, increasing its potential for reuse as an organic fertiliser. When grape marc and OFMSW are composted together, odour emissions are also found to be lower than when OFMSW is composted alone in similar circumstances (Muhlack et al., 2018).

Fernández et al. (2008) investigated the carbon biodegradation of exhausted grape marc in combination with other organic wastes using the turned pile composting system. Four different piles were built (exhausted grape marc, exhausted grape marc mixed with cow manure and straw, exhausted grape marc mixed with municipal solid waste and exhausted grape marc mixed with grape stalks). According to the results, co-composting significantly reduced the remanent amount of carbon after composting all of the piles while increasing the readily biodegradable carbon fractions from 35% when the exhausted grape marc was composted alone to 50 and 60% when the municipal solid waste or the grape stalks were added. Furthermore, the authors believe that grape stalks are the best option for co-composting with exhausted grape marc because of their availability in the winery, faster carbon biodegradation rates and higher quality of the final compost obtained.

VERMICOMPOSTING THE GRAPE MARC

Vermicomposting, unlike composting, is based on the cooperative action of detritivorous earthworms and microorganisms and does not include a thermophilic phase (Gómez-Brandón et al., 2019). The microorganisms play a role in the biochemical decomposition of organic matter by producing enzymes, whereas earthworms contribute to a greater population of microorganisms by fragmentation and ingestion of fresh organic matter (Vuković et al., 2021). The vermicomposting process involves two distinct phases in terms of earthworm activity: an active phase in which earthworms ingest, process and digest organic matter, thereby changing its physical-chemical and microbial composition and a maturation phase in which earthworms move towards fresher layers of the substrate while microorganisms decompose the earthworm-processed substrate (Gómez-Brandón et al., 2019; Lores et al., 2006). Compared to other waste management techniques, vermicomposting offers several advantages. For instance, it can be done both indoors and outdoors, enabling composting to occur all year round. In addition, this process allows for the production of organic nutrients for crops in less time, which are more nutritionally, physically and biochemically efficient than other composts (Alshehrei & Ameen, 2021; Rodríguez-Canché el al., 2010; Yadav et al., 2010). The final vermicompost quality is determined by a number of variables, including the earthworm species involved, the management techniques used, the length of the conditioning period and the chemical and physical properties of the substrate fed to the earthworms (Santana et al., 2020; Domínguez & Gómez-Brandón, 2013; Bisen et al., 2011).

Gómez-Brandón et al. (2020) investigated the feasibility of using vermicomposting for processing grape marc obtained from the red winemaking of Menca grapes for the purpose to produce a high-quality, polyphenol-free organic vermicompost that might be utilised as an environmentally friendly fertiliser. Their results indicate that the grape marc seems to be a good substrate for earthworm feeding, offering ideal growth and reproduction conditions as well as enough energy to support substantial populations. Additionally, the authors report that during the vermicomposting process, which lasted 112 days, earthworm activity helped to stabilise the grape marc, resulting in a final vermicompost that had a lower polyphenol content and a higher concentration of macro- and micronutrients. At the end of the composting process, lower microbial activity values were noted, which are indicating the stability of the compost.

Using 16S rRNA high-throughput sequencing, Kolbe et al. (2019) reported the first characterization of bacterial succession during white grape marc vermicomposting. To obtain the compost, the authors used a metal pilot-scale vermireactor, located in a greenhouse without any temperature control over the course of 91 days. Prior to adding the grape marc, the earthworms (*Eisenia andrei*) were placed in a 12 cm layer of vermicompost. After, a 12-centimeter layer of fresh grape marc was added to the bed. In order to facilitate earthworm migration and enable grape marc sampling, a plastic mesh was utilised to separate the vermicompost bedding from the fresh grape. This prevented processed grape marc from being mixed with the vermicompost bedding. The results of this study indicate that vermicomposting significantly alters the composition of bacterial communities and increases bacterial diversity, as well as the bacterial community's metabolic capacity or specific metabolic processes such as cellulose metabolism, plant hormone synthesis and antibiotic synthesis.

CONCLUSIONS

Composting is a biological process that converts organic waste into a material that can be used by plants. Grape marc, which is high in lignocellulosic compounds, is a valuable feedstock in green energy and compost production methods. Composting techniques such as aerated static piles, continuous vertical reactors and turned windrows can produce stabilised end products with defined stability and maturity characteristics. Co-composting grape marc with organic byproducts improves the quality of the final compost. Acidity is neutralised and compost dynamics are improved by adding materials such as grape stalks, animal manure or coffee grounds. Olive oil production residues combined with grape marc provide advantages such as low phytotoxicity and disease suppression. Exhausted grape marc combined with cattle or sheep manure can improve the soil biotic activity and nutrient content. Grape marc vermicomposting shows promise as it produces an organic vermicompost with increased nutrient concentration that is free of polyphenols. Overall, wineries can manage waste more efficiently, reduce their environmental impact and encourage the sustainable use of byproducts in a variety of applications by implementing composting and vermicomposting techniques as well as thoughtful co-composting practises.

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