

Review Article : Open Access

From vineyard to remedy: Medicinal attributes of Muscat Hamburg grapes

R. Sneha^{*♦}, V. Jegadeeswari^{**}, K. R. Vijayalatha^{***}, R. K. Kaleeswari^{****}, S. Nithila^{*****} and I. Muthuvel^{*****}^{*} Department of Fruit Science, Horticultural College and Research Institute for Women, Tamil Nadu Agricultural University, Trichy-620009, Tamil Nadu, India^{**} Grapes Research Station, Tamil Nadu Agricultural University, Theni-625526, Tamil Nadu, India^{***} Department of Vegetable Science, Horticultural College and Research Institute for Women, Tamil Nadu Agricultural University, Trichy-620009, Tamil Nadu, India^{****} Department of Natural Resource Management, Horticultural College and Research Institute for Women, Tamil Nadu Agricultural University, Trichy-620009, Tamil Nadu, India^{*****} Department of Basic Sciences, Horticultural College and Research Institute for Women, Tamil Nadu Agricultural University, Trichy-620009, Tamil Nadu, India^{*****} Department of Fruit Science, Horticultural College and Research Institute for Women, Tamil Nadu Agricultural University, Trichy-620009, Tamil Nadu, India

Article Info

Article history

Received 10 April 2025

Revised 24 May 2025

Accepted 25 May 2025

Published Online 30 June 2025

Keywords

Table grapes

Polyphenolic compounds

Antioxidant properties

Therapeutic applications

Bioactive metabolites

Abstract

Muscat Hamburg grapes are renowned for their rich phytochemical composition, including polyphenols, anthocyanins, and resveratrol, contributing to their significant phytomedicinal potential. This review explores their bioactive compounds, pharmacological properties, and health benefits, including antioxidant, anti-inflammatory, antimicrobial, and neuroprotective effects. The review also addresses key challenges, including low bioavailability, variability in phytochemical content, and regulatory constraints. Furthermore, it highlights recent advancements in extraction technologies and the development of innovative delivery systems aimed at enhancing the stability, efficacy, and therapeutic potential of grape-derived bioactives. Emerging research suggests their potential in managing chronic diseases like cardiovascular disorders, diabetes, and neurodegenerative conditions. Future prospects focus on nanotechnology, personalized nutrition, and sustainable utilization of grape by-products. With ongoing research and clinical validation, Muscat Hamburg grapes hold promise for therapeutic and industrial applications.

1. Introduction

The research on herbal medicines continues to be an essential part of pharmaceutical science, propelled by the need to discover new therapeutic molecules from nature. Plant-derived bioactive compounds have varied pharmacological activity, and hence they are of great interest for drug discovery and functional food products. Among these, Muscat Hamburg grapes, which are scientifically referred to as *Vitis vinifera* L., are remarkable because of their dense phytochemical content and presumed health advantages (Rasine *et al.*, 2017).

Muscat Hamburg grapes have long been prized for their unique odor, dark purple-black epidermis, and high sugar level, being grown for hundreds of years to be eaten fresh, used in winemaking, and to produce dried fruit (Aubert *et al.*, 2018). The dark color is due to anthocyanins, which have anti-inflammatory and anticancer effects. Another important constituent, resveratrol, has cardioprotective activity such as enhanced vascular function and inhibition of atherosclerosis. Apart from cardiovascular protection, resveratrol

has neuroprotective and antiageing effects, indicating its promise in the treatment of neurodegenerative disorders (Gal *et al.*, 2023).

Polyphenols derived from grapes possess notable antioxidant, lipid-regulating, anti-inflammatory, neuroprotective, and antimicrobial effects, making them promising agents for managing metabolic and neurological disorders (Kowalczyk *et al.*, 2024; Zhao *et al.*, 2020). Despite these benefits, their therapeutic potential is hindered by limited bioavailability due to poor absorption and rapid metabolic breakdown. Emerging technologies, including advanced extraction methods and nanocarrier-based delivery systems, are being developed to enhance their effectiveness (Rudrapal *et al.*, 2022). Muscat Hamburg grapes, known for their rich phytochemical profile, show significant potential in the development of functional foods, nutraceuticals, and pharmaceutical applications.

2. Phytochemical composition

Muscat Hamburg grapes are characterized by their complex phytochemical composition, having bioactive compounds such as polyphenols (flavonoids, anthocyanins, tannins), stilbenes (resveratrol), organic acids, and volatile compounds (Figure 1) and their health effects shown in (Table 1). They are responsible for sensory properties and express clinically important health effects (Miao *et al.*, 2022). Their composition is highly variable due to genetic and environmental factors (Table 4), stage of ripeness, and post-harvesting technologies (Kaya, 2024).

Corresponding author: Ms. R. Sneha

Department of Fruit Science, Horticultural College and Research Institute for Women, Tamil Nadu Agricultural University, Trichy-620009, Tamil Nadu, India

E-mail: srv.sneha2002@gmail.com

Tel.: +91-9361638635

Copyright © 2025 Ukaaz Publications. All rights reserved.

Email: ukaaz@yahoo.com; Website: www.ukaazpublications.com

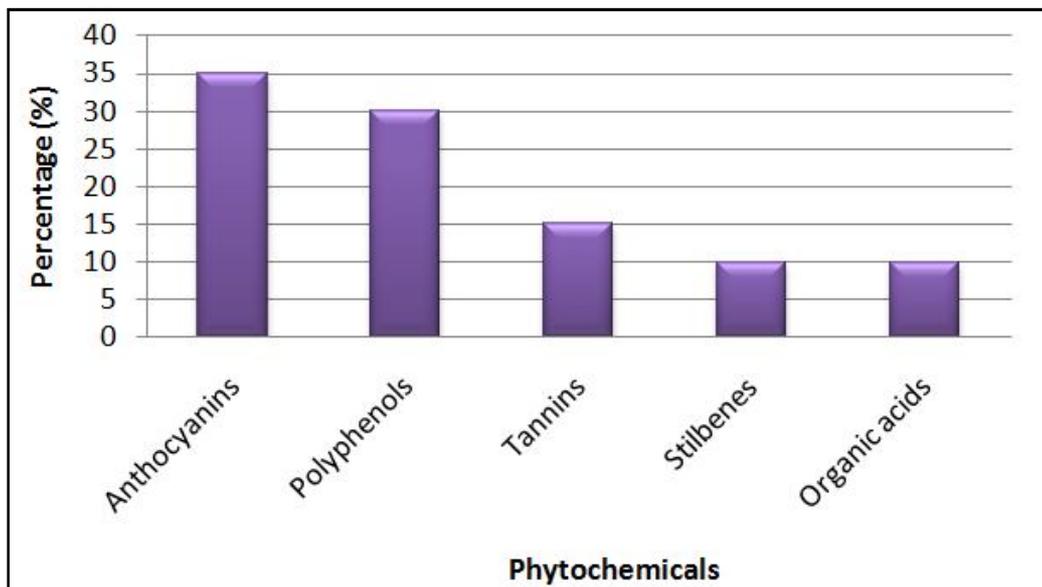


Figure 1: Major phytochemicals in Muscat Hamburg.

Table 1: Phytochemical composition and health effects of Muscat Hamburg grapes

Class	Example compounds	Concentration (fresh weight)	Health effects	References
Anthocyanins	Malvidin-3-glucoside	50-500 mg/kg	Antioxidant, anti-inflammatory	Silva <i>et al.</i> (2022)
Stilbenes	Resveratrol	0.1-10 mg/kg	Cardioprotective, antiageing	Rauf <i>et al.</i> (2023)
Flavonols	Quercetin-3-glucoside	5-50 mg/kg	Antidiabetic, anticancer	Doshi <i>et al.</i> (2021)
Tannins	Pro-anthocyanidin B ₁	100-2000 mg/kg	Antimicrobial	Pascual <i>et al.</i> (2020)
Organic acids	Tartaric acid	5-15 g/kg	pH regulation	Sanchez <i>et al.</i> (2023)
Volatile compounds	Linalool	0.1-5 mg/kg	Neuroprotective	Redondo <i>et al.</i> (2024)

2.1 Polyphenols

Polyphenols in Muscat Hamburg grapes play vital roles in defense mechanisms, cellular signaling, and biological processes. Found mainly in the skin, seeds, and pulp, their composition varies with environmental factors, ripeness, and post-harvest handling (Zhu *et al.*, 2017). These polyphenols are classified into flavonoids and non-flavonoids, each offering distinct bioactive properties in skin, seeds, and pulp are shown in (Table 2). These polyphenols are classified into flavonoids and non-flavonoids, each offering distinct bioactive properties. Flavonoids include flavan-3-ols, flavonols, and anthocyanins. Flavan-3-ols, such as catechin and epicatechin (20-50 mg/100 g), are abundant in the seeds and exhibit antioxidant, antimicrobial, and cardioprotective effects. Procyanidins, oligomers of flavan-3-ols, reduce oxidative stress and modulate lipid metabolism (Lu *et al.*, 2021). Flavonols, mainly quercetin, kaempferol, and myricetin (5-15 mg/100 g), are concentrated in the skin and show anti-inflammatory and anticarcinogenic properties, with levels increasing under UV exposure (Benmezziane *et al.*, 2016). Anthocyanins, responsible for the grape's deep purple-black color, include malvidin-3-O-glucoside, which constitutes 60-70% of total anthocyanins (200-500 mg/100 g). These compounds provide antioxidant and anti-inflammatory benefits (Chen *et al.*, 2024).

2.2 Anthocyanins

Anthocyanins are water-soluble flavonoid pigments responsible for the vibrant purple-to-black coloration in Muscat Hamburg grapes. These compounds belong to the larger polyphenol family and primarily accumulate in grape skins (85-90% of total content), where they function as photoprotective agents against UV radiation and microbial pathogens (Schaefer *et al.*, 2008; Balik *et al.*, 2013). Among the various anthocyanins present in Muscat Hamburg grapes, malvidin-3-O-glucoside is the most abundant, making up about 60-70% of the total anthocyanin content. Other notable anthocyanins include derivatives of delphinidin, petunidin, and cyanidin (Balik *et al.*, 2013).

Anthocyanins display multiple biological activities in humans. Their potent antioxidant action helps neutralize reactive oxygen species, reducing oxidative damage to cells. They also prevent the oxidation of low-density lipoprotein (LDL), which is an important factor in the progression of atherosclerosis. Furthermore, anthocyanins modulate inflammatory processes by influencing signaling pathways such as NF- κ B and cyclooxygenase (COX), resulting in decreased production of inflammatory cytokines. Notably, these pigments can cross the blood-brain barrier and protect neurons from damage,

potentially slowing the development of neurodegenerative diseases (Satue-Gracia *et al.*, 1997; Winter *et al.*, 2019). Although, these effects highlight the potential health benefits of anthocyanins, most supporting research comes from laboratory and animal models. Clinical trials involving humans remain limited and often yield

inconsistent results due to differences in absorption, metabolism, and dosage. Therefore, more rigorous human studies are necessary to verify the therapeutic effects of anthocyanins and to guide their clinical application and dietary recommendations (Huang *et al.*, 2023).

Table 2: Polyphenol distribution in Muscat Hamburg grape tissues

Tissue	Subclass	Key compounds	Concentration (mg/100 g FW)	Primary bioactivities	References
Seeds	Flavan-3-ols	Catechin, Epicatechin	20-50	Antioxidant, cardioprotective	Lu <i>et al.</i> (2021)
	Phenolic acids	Gallic acid, Caffeic acid	3-8	Antimicrobial	Salehi <i>et al.</i> (2018)
Skin	Anthocyanins	Malvidin-3-O-glucoside	200-500	Anti-inflammatory, antioxidant	Chen <i>et al.</i> (2024)
	Flavonols	Quercetin, Kaempferol	5-15 (UV-exposed: 30-50%)	Anticarcinogenic	Benmeziene <i>et al.</i> (2016)
Pulp	Stilbenes	Resveratrol	1-5	Neuroprotective, antiageing	Salehi <i>et al.</i> (2018)
	Hydroxycinnamates	Ferulic acid	1-3	Antioxidant	Zhu <i>et al.</i> (2017)

2.3 Tannins

Tannins are polyphenolic compounds that are predominantly found in the skins, seeds, and stems of Muscat Hamburg grapes, where they perform vital functions by providing astringency and improving the aging attributes of wine and other grape products (McRae and Kennedy, 2011). Muscat Hamburg grapes are enriched in condensed tannins, also known as proanthocyanidins that are formed from the flavan-3-ols catechin and epicatechin (Sabra *et al.*, 2021). From the perspective of human health, tannins provide numerous benefits including antioxidant, anti-inflammatory, and anticancer effects. Proanthocyanidins act as antioxidants by neutralizing reactive oxygen species (ROS) and binding metal ions which catalyze oxidative reactions. This activity reduces oxidative stress and triggers cardiovascular health benefits. It has been demonstrated that proanthocyanidins can prevent the oxidation of low-density lipoprotein (LDL) cholesterol, which is essential in the formation of atherogenic plaques (Mazur *et al.*, 1999). Tannins have been shown to affect cancer by inducing programmed cell death in tumor cells, inhibiting angiogenesis (formation of blood vessels), and inhibiting molecular pathways that allow uncontrolled cellular growth (Youness *et al.*, 2021).

2.4 Stilbenes

Stilbenes, including resveratrol (trans-3,5,4'-trihydroxystilbene), are polyphenolic compounds predominantly produced in the skin of Muscat Hamburg grapes. Their synthesis is triggered by environmental stresses such as ultraviolet (UV) light, fungal infections, and physical damage. This natural stress response not only helps protect the grapevine but also opens up possibilities for agricultural and biotechnological approaches aimed at boosting stilbene levels such as applying controlled stress or genetic modification to enhance both plant health and the nutritional value of grapes (Sun *et al.*, 2023). The active form of resveratrol, the trans-isomer, is recognized for its strong antioxidant and anti-inflammatory actions, which contribute to cardiovascular protection by lowering oxidative stress

and guarding cells against damage linked to aging and chronic diseases (Drago *et al.*, 2024; Cheng *et al.*, 2022). One important way resveratrol works is by activating the SIRT1 pathway, an enzyme that depends on NAD⁺ and plays a critical role in controlling metabolism, DNA repair, and lifespan. Stimulating SIRT1 improves mitochondrial efficiency, enhances insulin sensitivity, and regulates inflammation, making resveratrol a potential therapeutic agent for ageing related metabolic conditions (Rogina and Tissenbaum, 2024). However, the practical use of resveratrol in medicine is hindered by its low bioavailability due to rapid metabolism and clearance. To address this, researchers are exploring techniques such as encapsulating resveratrol in nanoparticles or liposomes, and combining it with substances like piperine that slow its breakdown to improve absorption. Moreover, consuming whole grapes or grape-based products may enhance its uptake by providing a natural matrix that facilitates better resveratrol availability (Rege *et al.*, 2014).

2.5 Organic acids

Organic acids are essential constituents of Muscat Hamburg grapes, playing a crucial role in determining their flavor profile, aromatic characteristics, and natural preservative properties are shown in (Table 3). The predominant organic acids present are tartaric acid and malic acid, which together constitute the majority of the total acidity in the fruit. The main organic acids found in Muscat Hamburg grapes are tartaric acid and malic acid, which together account for the majority of the fruit's acidity. Tartaric acid predominates, imparting a sharp and crisp flavor, whereas malic acid contributes a softer, fruitier taste (Vujovic *et al.*, 2017; Kunter *et al.*, 2024). In addition, smaller amounts of secondary acids like citric acid and oxalic acid help regulate the grape's pH balance (Yinshan *et al.*, 2017). Beyond their role in shaping flavor and aroma, these organic acids possess antioxidant and antimicrobial effects that contribute to the preservation and nutritional quality of grape products. Their levels can fluctuate based on environmental conditions, farming techniques, and the stage of grape ripeness (Rogiers *et al.*, 2022).

Table 3: Organic acid composition and functional roles in Muscat Hamburg grapes

Organic acid	Concentration range	Physiological effect	References
Tartaric acid	Highest, major contributor	Sharp taste, antioxidant, antimicrobial	Vujovic <i>et al.</i> (2017); Kunter <i>et al.</i> (2024)
Malic acid	High	Milder, fruity flavor; antioxidant, antimicrobial	
Citric acid	Low	pH regulation, antioxidant	Yinshan <i>et al.</i> (2017)
Oxalic acid	Trace amounts		

2.6 Volatile and organic compounds

Distinct from organic acids that mainly affect taste and preservation, volatile organic compounds (VOCs) are key contributors to the unique aroma and flavor of Muscat Hamburg grapes. These compounds are vital in shaping the sensory experience of the fruit and its derived products. VOCs include various chemical classes such as monoterpenes, nor-isoprenoids, alcohols, aldehydes, and esters (Fenoll *et al.*, 2009). Monoterpenes like linalool, geraniol, and nerol provide floral and fruity scents. Typically stored as inactive glycosides within the grapes, they are released during ripening and fermentation, which enhances the aroma (Parker *et al.*, 2018). Nor-isoprenoids such as β -damascenone and β -ionone contribute fruity, honeyed, and woody notes that intensify with grape maturity (Tomasino and Bolman, 2021). Alcohols like benzyl alcohol and phenylethyl alcohol add sweet, rose-like aromas, while esters including ethyl acetate impart fruity and tropical flavors (Bayram and Kayalar, 2020). The levels and types of VOCs are heavily influenced by environmental conditions like climate, soil, and viticultural techniques. Besides their influence on aroma and flavor,

many VOCs possess antioxidant and antimicrobial properties, which can enhance the grapes' health benefits and preservation capacity (Deis *et al.*, 2024).

3. Phytomedicinal properties

Muscat Hamburg grapes are rich in various bioactive compounds that offer multiple phytomedicinal benefits, including antioxidant, anti-inflammatory, anticancer, cardioprotective, neuroprotective, and antimicrobial effects. (Figure 2) provides a summary chart that highlights important health properties of Muscat Hamburg. These health-promoting effects are primarily attributed to the presence of a diverse array of bioactive compounds, including polyphenols, flavonoids, anthocyanins, tannins, stilbenes, and organic acids. These constituents collectively contribute to the prevention and management of various chronic diseases through their antioxidant, anti-inflammatory, and metabolic regulatory activities (Sabra *et al.*, 2021). Table 5 presents the levels of bioactive compounds in Muscat Hamburg grapes at various stages of ripeness.

Table 4: Environmental factors influencing phytochemical composition in Muscat Hamburg grapes

Environmental factor	Effect on bioactive compounds	Mechanism of influence	Optimal conditions	Industrial implications	References
Temperature	Increases anthocyanin and resveratrol synthesis	Stimulates phenyl-propanoid pathway	25-30°C during ripening for higher polyphenol content	High-temperature regions produce grapes with superior antioxidant properties	Goufo <i>et al.</i> (2020)
Sunlight exposure	Enhance flavonoid and anthocyanin accumulation	Activates UV-induced secondary metabolite biosynthesis	Moderate UV-B exposure improves pigmentation	Sun-exposed grapes yield richer anthocyanin for cosmetics and nutraceutical	Zhang <i>et al.</i> (2024)
Soil composition	Affects phenolic acid and tannin concentration	Mineral bioavailability influences biosynthetic pathways	Calcium rich, slightly acidic soil (pH 5.5-6.5)	Mineral-enriched soils boost polyphenol production for medicinal use	Wang <i>et al.</i> (2022)
Irrigation practices	Increases stilbene (resveratrol) content	Water stress activates defense-related pathways	Regulated deficit irrigation enhances phytochemical yield	Controlled irrigation enhances antioxidant-rich grape extracts for pharmaceutical use	Shen <i>et al.</i> (2021)
Pesticide use	Reduces total phenolic and anthocyanin content	Inhibits secondary metabolite pathways	Organic or minimal pesticide application preferred	Organically cultivated grapes maintain high phytochemical integrity for health products	Dangelo <i>et al.</i> (2022)

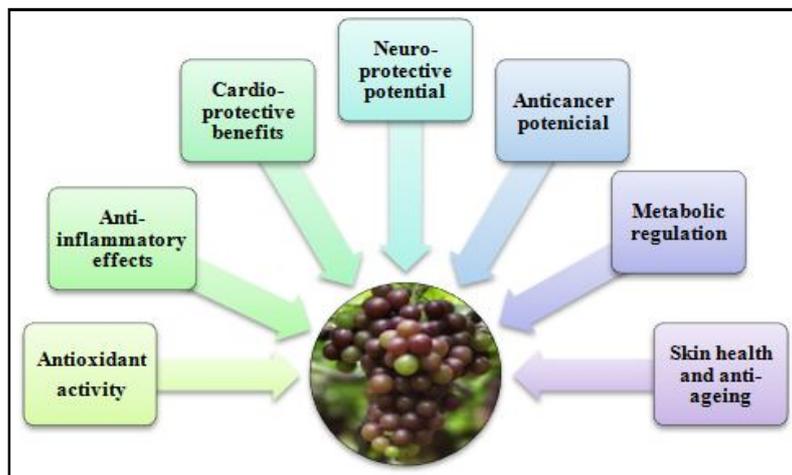


Figure 2: Phytochemical properties of Muscat Hamburg.

3.1 Antioxidant properties

Muscat Hamburg grapes exhibit strong antioxidant capacity due to their high levels of anthocyanins, flavonoids, and resveratrol. These compounds act as free radical scavengers, reducing reactive oxygen species (ROS) and protecting against oxidative stress and cellular damage (Mota *et al.*, 2018). Anthocyanins, especially malvidin-3-glucoside, inhibit lipid peroxidation, protect cell membranes, and improve vascular health by reducing oxidative inflammation and enhancing endothelial function (Brown and Kelly, 2007; Huang *et al.*, 2014).

3.2 Anti-inflammatory effects

Inflammation is a multifaceted process involving interactions between cells and soluble factors like cytokines, which can occur in any tissue following traumatic, infectious, post-ischemic, toxic, or autoimmune damage (Barathiet *et al.*, 2024). Muscat Hamburg grapes exhibit anti-inflammatory properties by modulating inflammatory pathways and suppressing key pro-inflammatory mediators such as cytokines and prostaglandins. Polyphenols inhibit enzymes like cyclooxygenase-2 (COX-2) and lipoxygenase (LOX), which are responsible for inflammatory responses (Gal *et al.*, 2023). This inhibitory action reduces inflammation linked to chronic conditions like arthritis, inflammatory bowel disease, and atherosclerosis (Rudrapal *et al.*, 2023).

3.3 Anticancer potential

Several bioactive compounds in Muscat Hamburg grapes, particularly resveratrol and anthocyanins, demonstrate anticancer properties. These compounds exert their effects through various mechanisms, including inducing apoptosis, inhibiting cell proliferation, and preventing metastasis (Cotino *et al.*, 2023). Resveratrol triggers programmed cell death by activating caspase enzymes and disrupting cancer cell cycles (Bhardwaj *et al.*, 2007).

3.4 Cardioprotective effects

The cardioprotective properties of Muscat Hamburg grapes are linked to their ability to improve vascular function, lower cholesterol levels, and prevent atherosclerosis. Resveratrol is particularly effective in reducing low-density lipoprotein (LDL) oxidation, which is a major contributor to plaque formation in arteries (Voloshyn *et al.*, 2012).

Polyphenols in Muscat Hamburg grapes also modulate blood pressure and improve circulation by enhancing nitric oxide (NO) production, which promotes vasodilation (Rasines *et al.*, 2007). Long-term consumption of grape polyphenols has been shown to reduce the risk of hypertension, stroke, and myocardial infarction (Cheng *et al.*, 2007).

3.5 Neuroprotective properties

Recent studies suggest that Muscat Hamburg grapes exhibit neuroprotective properties by reducing oxidative damage and inflammation in the brain. Polyphenols, especially anthocyanins and resveratrol, can cross the blood-brain barrier, protect neurons from degeneration, and inhibit β -amyloid plaque aggregation, a key feature of Alzheimer's disease while enhancing synaptic plasticity (Shimazu *et al.*, 2021; Rege *et al.*, 2015). Additionally, these compounds may improve cognitive function by modulating neurotransmitters like acetylcholine and preventing oxidative-induced neurotoxicity (Basli *et al.*, 2012).

3.6 Antimicrobial activity

The antimicrobial properties of Muscat Hamburg grapes are mainly attributed to their tannins, flavonoids, and organic acids. These compounds inhibit the growth of pathogenic bacteria, fungi, and viruses by disrupting microbial cell membranes and biofilm formation (Miao *et al.*, 2022). Studies show that grape seed extracts exhibit strong activity against *Staphylococcus aureus*, *Escherichia coli*, and *Candida albicans* (Kandasamy *et al.*, 2016). The antimicrobial potential of Muscat Hamburg grapes has applications in food preservation and pharmaceuticals, providing natural alternatives to synthetic antimicrobials (Nirmala *et al.*, 2011).

3.7 Regulation of metabolic disorders

Muscat Hamburg grapes may also help regulate metabolic disorders, including diabetes and obesity, by improving insulin sensitivity, lowering blood glucose levels, and modulating lipid metabolism (Zunino, 2009). Polyphenols activate the AMP-activated protein kinase (AMPK) pathway, which enhances glucose uptake and fatty acid oxidation (Srivastava *et al.*, 2012). Resveratrol has been shown to reduce adipogenesis and inflammation in adipose tissue, making it beneficial for managing obesity-related complications (Zagotta *et al.*, 2015).

Table 5: Bioactive content of Muscat Hamburg grapes at different maturity stages

Maturity Stage	Anthocyanin (mg/100 g)	Polyphenols (mg/kg)	Resveratrol (mg/kg)	Tannins (mg/kg)	Organic acids (g/l)	Phytomedicinal potential	References
Immature (Green stage)	5-10	150-200	<0.5	80-100	Tartaric acid (1.5-2.0), Malic acid (2.5-3.0)	Antimicrobial, astringent, promotes gut health	Patel <i>et al.</i> (2021)
Mid-ripening (Pink stage)	15-25	250-300	1-2	50-70	Tartaric acid (1.2-1.8), Malic acid (2.0-2.5)	Antioxidant, anti-inflammatory, boosts immunity	Wang <i>et al.</i> (2022)
Fully ripe (Black stage)	40-50	300-400	2.5-4	20-40	Tartaric acid (0.5-1.0), Malic acid (1.0-1.5)	Cardioprotective, neuroprotective, antiageing	Shen <i>et al.</i> (2023)
Overripe (Shriveled stage)	20-30	200-250	4-6	<20	Tartaric acid (<0.5), Malic acid (<1.0)	Metabolic regulation improves cognitive functions	Zhang <i>et al.</i> (2024)

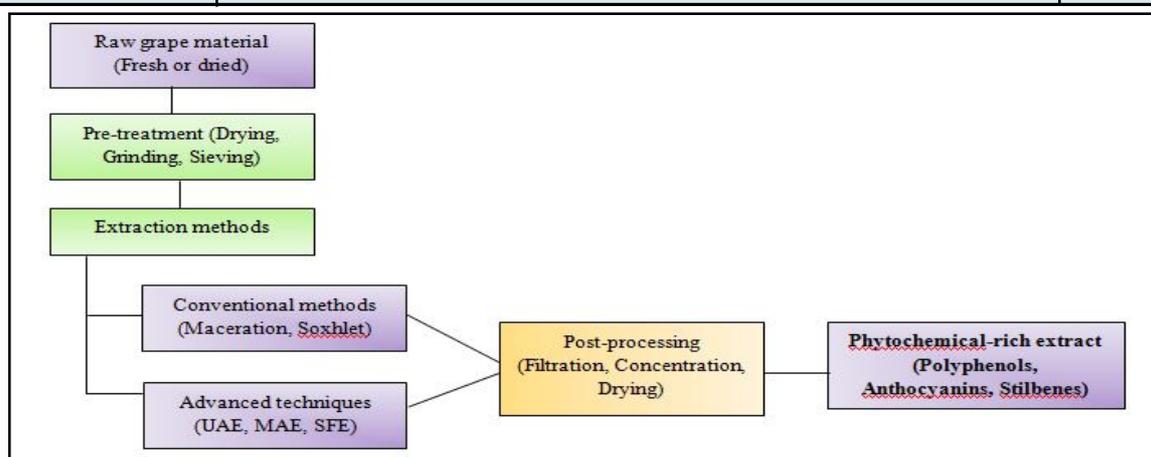
4. Extraction methods and bioavailability of phytochemicals in Muscat Hamburg grapes

Muscat Hamburg grapes contain various phytochemicals such as polyphenols, anthocyanins, tannins, stilbenes, and organic acids, which are extracted using both traditional and advanced methods. The choice of extraction technique significantly affects the quantity, purity, and bioavailability of these compounds. (Figure 3) shows a flowchart of the general extraction process. Table 6 outlines innovative extraction techniques and compares their effectiveness: for instance,

ultrasound assisted extraction often results in higher anthocyanin yields due to enhanced cell disruption, whereas microwave-assisted extraction is more efficient for recovering stilbenes like resveratrol. Supercritical fluid extraction provides high-purity extracts of tannins and organic acids, although it is less commonly used. These variations underscore the importance of selecting the appropriate extraction method based on the specific phytochemical targeted to achieve the best results (Delic *et al.*, 2024).

Table 6: Innovative extraction techniques for phytochemicals in Muscat Hamburg grapes

Extraction technique	Mechanism	References
Reduced pressure extraction (RPE)	Utilizes low pressure to lower solvent boiling points, limiting thermal degradation. Effectively extracts polyphenols from grape skins, maintaining their bioactivity while reducing solvent consumption and extraction time.	Yilmaz and Gokeman (2023)
Green extraction techniques	Eco-friendly methods like ultrasound-assisted extraction (UAE), microwave assisted extraction (MAE), and pressurized liquid extraction (PLE) enhance efficiency while minimizing environmental impact. UAE uses ultrasonic waves to disrupt cell walls, MAE applies microwave radiation for rapid heating, and PLE utilizes high pressure to improve compound solubility.	Chemat <i>et al.</i> (2022)
Natural deep eutectic solvents (NaDES)	Employs biodegradable, non-toxic solvents such as organic acids and sugars to efficiently extract heat sensitive compounds like anthocyanins and flavonoids, offering a safer, sustainable alternative to traditional solvents.	Paiva <i>et al.</i> (2023)
Medium scale ambient temperature (MSAT) extraction	Uses GRAS solvents at ambient temperature to preserve heat-sensitive compounds like anthocyanins; energy-efficient, cost effective, and ideal for large scale extraction.	Rodriguez <i>et al.</i> (2022)
Ultrasound assisted enzymatic extraction (UAEE)	Integrates ultrasound and enzymes to break cell walls, boosting anthocyanin yield, reducing processing time, and enhancing bioactivity; suitable for both research and industrial use.	Wang <i>et al.</i> (2023)

**Figure 3: Extraction of phytochemicals from Muscat Hamburg flowchart.**

5. Clinical evidence and human trials on Muscat Hamburg grape polyphenols

Recent clinical research highlights the therapeutic potential of grape-derived polyphenols, including those found in Muscat Hamburg grapes, for managing metabolic disorders and chronic diseases (Joel *et al.*, 2024).

5.1 Muscle health enhancement

A study showed that consuming the equivalent of two servings of Muscat Hamburg grapes daily modulated the expression of over 20,000 genes related to muscle health in elderly mice, suggesting potential benefits for muscle preservation in aging humans (Dave *et al.*, 2025).

5.2 Cardiovascular and metabolic health

A meta-analysis of randomized clinical trials indicated that Muscat Hamburg grape polyphenols reduce oxidative stress, contributing to the prevention and management of cardiovascular diseases and type 2 diabetes (Sarkhosh *et al.*, 2021).

5.3 Anti-inflammatory effects

Human studies reveal that Muscat Hamburg grape seed polyphenol supplementation significantly lowers C-reactive protein (CRP) levels, a marker of inflammation, though further large-scale trials are needed to confirm these effects (Sarkhosh and Hosseinzadeh, 2021).

5.4 Cancer prevention potential

The ongoing Colo-Prevent trial in the UK suggests that resveratrol from red and black grapes (Muscat Hamburg) may slow the progression of precancerous polyps and reduce colorectal cancer risk, offering promise for resveratrol-based preventive strategies (Cancer research UK, 2024).

5.5 Metabolic protection

A one-month human trial demonstrated that Muscat Hamburg grape polyphenol-rich extract protects against metabolic dysfunction caused by overfeeding, helping maintain glucose homeostasis and improving lipid profiles (Segrestin *et al.*, 2022).

6. Potential applications of Muscat Hamburg grapes in medicine and industry

Muscat Hamburg grapes are rich in bioactive compounds such as polyphenols, anthocyanins, flavonoids, and resveratrol, which offer

diverse applications in both medical and industrial fields (Sabra *et al.*, 2021).

6.1 Medical applications

Their antibacterial activity, particularly from grape seed extracts, shows potential for developing natural antimicrobial agents. Postharvest treatments, such as ozone exposure, effectively reduce fungal infections while preserving bioactive content, and maintaining therapeutic potential during storage (Rio *et al.*, 2017). Additionally, the polyphenolic content aids in managing metabolic syndromes and may provide neuroprotective benefits against neurodegenerative diseases (Hokayem *et al.*, 2013).

6.2 Industrial applications

Muscat Hamburg grapes are utilized in various industries for wine production, nutraceuticals, cosmetics, functional foods, and natural preservatives (Figure 4) due to their rich phytochemical content. In the food industry, Muscat Hamburg grape extracts serve as natural preservatives, inhibiting microbial growth and extending shelf life without synthetic additives (Nirmala *et al.*, 2011). In wine production, advanced fermentation techniques enhance the aromatic profile and sensory quality of Muscat Hamburg wines, increasing their market appeal (Zhang *et al.*, 2019). The cosmetic industry utilizes grape polyphenols for their antioxidant and skin-protective properties, contributing to the formulation of antiageing creams and other skincare products (Ndiaye *et al.*, 2011). Furthermore, the valorization of grape by-products supports sustainable practices by repurposing waste materials for bioactive-rich extracts in both food and cosmetics (Sodhi *et al.*, 2024).

6.3 Regulatory and commercialization hurdles

Despite achieving GRAS (Generally Recognized as Safe) designation in the United States for daily doses of up to 1 gram (U.S. FDA, 2022), resveratrol products encounter significant development challenges. Maintaining compound stability during manufacturing processes remains problematic, particularly due to heat sensitivity above 40°C (Singh and Pai, 2023). Furthermore, obtaining regulatory approval for specific health claims requires more robust clinical evidence of efficacy (EFSA Panel on Nutrition, 2022). To overcome these barriers, advanced delivery systems such as encapsulation technologies are being implemented (Davidov-Pardo and McClements, 2024), which aim to enhance bioavailability a well-documented limitation in human studies (Smoliga and Blanchard, 2023).

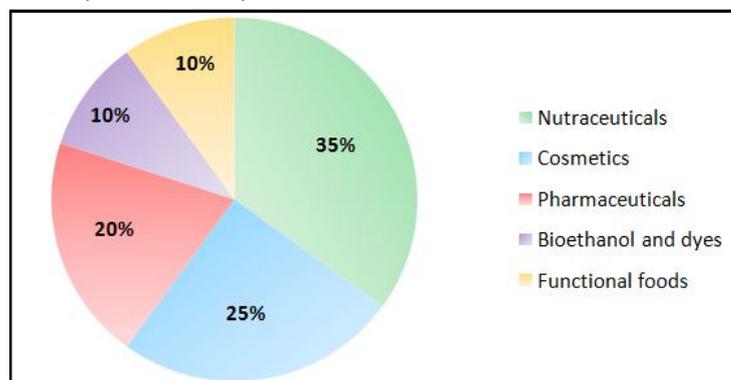


Figure 4: Industrial applications of Muscat Hamburg.

7. Challenges and future prospects

Muscat Hamburg grapes are rich in polyphenols and anthocyanins, offering significant health benefits, but their therapeutic potential is often limited by low bioavailability and considerable variation in phytochemical levels (Shen *et al.*, 2022). Environmental influences, harvest timing, and processing methods contribute to these inconsistencies, which can affect their effectiveness (Ogwu *et al.*, 2025). Although nanotechnology techniques like nanoencapsulation and liposomal delivery show promise in enhancing stability and targeted absorption, practical application challenges remain (Cheng *et al.*, 2025). Additionally, the lack of extensive human clinical trials hinders regulatory approval and widespread use, highlighting the need for further research to verify safety and efficacy (Alemayehu *et al.*, 2018). Future directions focus on improving bioavailability through advanced delivery systems, personalizing nutrition strategies, sustainable utilization of grape by-products, and employing precision agriculture to better control phytochemical content (Yadav *et al.*, 2023).

8. Conclusion

Muscat Hamburg grapes contain a wealth of bioactive compounds and hold strong potential for use in phytomedicine. Although findings from broader grape studies are informative, dedicated research on the Muscat Hamburg cultivar is crucial to substantiate health-related claims specific to this variety. Limitations such as poor bioavailability, inconsistent phytochemical profiles, and regulatory constraints continue to pose challenges. Emerging technologies like nanodelivery systems, personalized nutrition approaches, and sustainable agricultural methods present viable solutions. To fully realize the therapeutic potential of Muscat Hamburg grapes, further cultivar-specific investigations and large-scale clinical trials are needed. With focused scientific efforts and continued innovation, this grape variety could significantly contribute to advancements in both the healthcare and industrial sectors.

Conflict of interest

The authors declare no conflicts of interest relevant to this article.

References

- Alemayehu, C.; Mitchell, G. and Nikles, J. (2018). Barriers for conducting clinical trials in developing countries A systematic review. *International Journal for Equity in Health*, **17**(1):37. <https://doi.org/10.1186/s12939-018-0748-6>
- Aubert, C. and Chalot, G. (2018). Chemical composition, bioactive compounds, and volatiles of six table grape varieties (*Vitis vinifera* L.). *Food Chemistry*, **240**:524-533. <https://doi.org/10.1016/j.foodchem.2017.07.152>.
- Balik, J.; Kumsta, M. and Rop, O. (2013). Comparison of anthocyanins present in grapes of *Vitis vinifera* L. varieties and interspecific hybrids grown in the Czech Republic. *Chemical Papers*, **67**(10):1285-1292. <https://doi.org/10.2478/s11696-013-0378-9>
- Barathi, R.; Rajangam, J.; Muthuramalingam, S.; Anitha, T. and Venkatesan, K. (2024). Unveiling the pharmaceutical and cosmetological applications of phytoconstituents in Dragon fruit: A review. *Ann. Phytomed.*, **13**(2):119-130. <https://doi.org/10.54085/ap.2024.13.2.12>.
- Basli, A.; Soulet, S.; Chaher, N.; Merillon, J. M.; Chibane, M.; Monti, J. P. and Richard, T. (2012). Wine polyphenols: Potential agents in neuroprotection. *Oxidative Medicine and Cellular Longevity*, **2012**. <https://doi.org/10.1155/2012/805762>.
- Bayram, M. and Kayalar, M. (2018). White wines from Narince grapes: Impact of two different grape provenances on phenolic and volatile composition. *Oeno One*, **52**(2):81-92.
- Benmeziane, F.; Cadot, Y.; Djamai, R. and Djermoun, L. (2016). Determination of major anthocyanin pigments and flavonols in red grape skin of some table grape varieties (*Vitis vinifera* sp.) by high-performance liquid chromatography-photodiode array detection (HPLC-DAD). *Oeno One*, **50**(3):125-135.
- Bhardwaj, A.; Sethi, G.; Vadhan Raj, S.; Bueso Ramos, C.; Takada, Y.; Gaur, U.; Nair, A. S.; Shishodia, S. and Aggarwal, B. B. (2007). Resveratrol inhibits proliferation, induces apoptosis, and overcomes chemoresistance through down regulation of STAT3 and nuclear factor κB regulated antiapoptotic and cell survival gene products in human multiple myeloma cells. *Blood*, **109**(6):2293-2302. <https://doi.org/10.1182/blood-2006-02-003988>
- Brown, J. E. and Kelly, M. F. (2007). Inhibition of lipid peroxidation by anthocyanins, and their phenolic degradation products. *European Journal of Lipid Science and Technology*, **109**(1):66-71. <https://doi.org/10.1002/ejlt.200600166>
- Cancer Research UK. (2024). A trial looking at aspirin, metformin and resveratrol to prevent bowel polyps (CoLo-prevent). <https://www.cancerresearchuk.org/about-cancer/find-a-clinical-trial/a-trial-looking-at-aspirin-metformin-and-resveratrol-to-prevent-bowel-polyps-colo-prevent>
- Chen, H.; Wang, M.; Zhang, L.; Ren, F.; Li, Y.; Chen, Y.; Liu, Y.; Zhang, Z. and Zeng, Q. (2024). Anthocyanin profiles and color parameters of fourteen grapes and wines from the eastern foot of Helan Mountain in Ningxia. *Food Chemistry*: **24**. <https://doi.org/10.1016/j.foodchem.2024.102034>.
- Cheng, C. K.; Luo, J.Y.; Lau, C. W.; Chen, Z.Y.; Tian, X. Y. and Huang, Y. (2020). Pharmacological basis and new insights of resveratrol action in the cardiovascular system. *British Journal of Pharmacology*, **177**(6):1258-1277. <https://doi.org/10.1111/bph.14801>.
- Cheng, Y.C.; Sheen, J.M.; Hu, W. L. and Hung, Y.C. (2017). Polyphenols and oxidative stress in atherosclerosis related ischemic heart disease and stroke. *Oxidative Medicine and Cellular Longevity*, **2017**. <https://doi.org/10.1155/2017/8526438>.
- Cheng, Z.; Huang, H.; Yin, M. and Li, Y. (2025). Applications of liposomes and lipid nanoparticles in cancer therapy: Current advances and prospects. *Experimental Hematology and Oncology*, **14**. <https://doi.org/10.1186/s40164-025-00602-1>.
- CotinoNajera, S.; Herrera, L. A.; Dominguez Gomez, G. and Diaz Chavez, J. (2023). Molecular mechanisms of resveratrol as chemo and radiosensitizer in cancer. *Frontiers in Pharmacology*, pp:14
- D Rege, S.; Geetha, T.; L Broderick, T. and Ramesh Babu, J. (2015). Resveratrol protects β amyloid-induced oxidative damage and memory associated proteins in H19-7 hippocampal neuronal cells. *Current Alzheimer Research*, **12**(2):147-156.
- Dangelo, S.; Martino, E., and Armentano, A. (2022). Polyphenols: Potential use in the prevention and treatment of chronic diseases. *Journal of Functional Foods*, pp:90.
- Dave, A.; Park, E.J.; Piya, S., and Pezzuto, J. M. (2025). Long-term dietary consumption of grapes alters phenotypic expression in skeletal muscle of aged male and female mice. *Foods*, **14**(4):695. <https://doi.org/10.3390/foods14040695>.

- Davidov-Pardo, G., and McClements, D. J. (2024). Nutraceutical delivery systems: Resveratrol encapsulation and controlled release. *Food Chemistry*, **405**(B):135922. <https://doi.org/10.1016/j.foodchem.2023.135922>.
- Deis, L.; Martínez, L.; Da Costa, B. S., and Vilanova, M. (2024). The Influence of climatic conditions associated with altitude on the volatile composition of Cabernet Sauvignon wines from Argentina, Spain and Portugal. *Horticulturae*, **10**(8):870. <https://doi.org/10.3390/horticulturae10080870>.
- Delic, K.; Milincic, D. D.; Pesic, M. B.; Levic, S.; Nedovic, V. A.; Gancel, A. L. and Teissedre, P. L. (2024). Grape, wine and pomaceanthocyanins: Winemaking biochemical transformations, application and potential benefits. *Oeno One*, **58**(4).
- Doshi, P.; Adsule, P.; Banerjee, K. and Oulkar, D. (2021). Phenolic composition and antioxidant activity in grapevine parts and berries (*Vitis vinifera* L.) cv. Cabernet Sauvignon, Pinot Noir and Merlot grown in Indian conditions. *Journal of Food Science and Technology*, **58**(3):1159-1168. <https://doi.org/10.1007/s13197-020-04629-6>.
- Drago, L.; Ciprandi, G.; Brindisi, G.; Brunese, F. P.; Dinardo, G.; Gori, A.; Indolfi, C.; Naso, M.; Tondina, E.; Trincianti, C.; Varricchio, A.; Zicari, A. M.; Ullah, H.; Daglia, M. and The Nutraceutical, Medical Device Task Force of the Italian Society of Pediatric Allergy, Immunology (SIAIP) (2024). Certainty and uncertainty in the biological activities of resveratrol. *Food Frontiers*, **5**:849-854. <https://doi.org/10.1002/fft2.375>.
- EFSA panel on nutrition.(2022). Safety of trans-resveratrol as a novel food. *EFSA Journal*, **20**(1):e07035. <https://doi.org/10.2903/j.efsa.2022.7035>.
- Fenoll, J.; Manso, A.; Hellin, P.; Ruiz, L. and Flores, P. (2009). Changes in the aromatic composition of the *Vitis vinifera* grape Muscat Hamburg during ripening. *Food Chemistry*, **114**(2):420-428.
- Gal, R.; Halmosi, R.; Gallyas, F.; Jr.; Tschida, M.; Mutirangura, P.; Toth, K.; Alexy, T. and Czopf, L. (2023). Resveratrol and beyond: The effect of natural polyphenols on the cardiovascular system: A narrative review. *Biomedicines*, **11**(11):2888. <https://doi.org/10.3390/biomedicines11112888>.
- Goufo, P.; Singh, R. K. and Cortez, I. (2020). A comparative study on phenolic composition and antioxidant activity of red and white grapes. *Food Chemistry*, **315**:126-297. <https://doi.org/10.1016/j.foodchem.2020.126297>.
- Hokayem, M.; Blond, E.; Vidal, H.; Lambert, K.; Meugnier, E.; Feillet-Coudray, C.; Coudray, C.; Pesenti, S.; Luyton, C.; Lambert Porcheron, S.; Sauvignet, V.; Fedou, C.; Brun, J. F.; Rieusset, J.; Bisbal, C.; Sultan, A.; Mercier, J.; Goudable, J.; Dupuy, A. M.; Cristol, J. P. and Avignon, A. (2013). Grape polyphenols prevent fructose-induced oxidative stress and insulin resistance in first-degree relatives of type 2 diabetic patients. *Diabetes Care*, **36**(6):1454-1461. <https://doi.org/10.2337/dc12-1652>.
- Huang, W. Y.; Liu, Y. M.; Wang, J.; Wang, X. N. and Li, C. Y. (2014). Anti-inflammatory effect of the blueberry anthocyaninsmalvidin-3-glucoside and malvidin-3-galactoside in endothelial cells. *Molecules* (Basel, Switzerland), **19**(8):12827-12841. <https://doi.org/10.3390/molecules190812827>.
- Huang, W.; Sui, Z. and Zhang, W. (2023). Advances in anthocyanins: Sources, preparation, analysis methods, bioavailability, physicochemical properties, and structural features. *Frontiers in Nutrition*, **10**:1148051.
- Joel Robin, S.; Balakumbahan, R.; Rajesh, S.; Muthulakshmi, S. and Anitha, T. (2024). Exploring the bioactive components and their pharmacological prospects in Avocado (*Persea americana* Mill.). *Ann. Phytomed.*, **13**(2):394-407. <https://doi.org/10.54085/ap.2024.13.2.38>.
- Kandasamy, M.; Nasimuddin, S.; Malayan, J.; Nithyalakshmi, J.; Gnanadesikan, S. and Chandrasekar, M. (2016). A study on antibacterial effect of grape seed extracts in common clinical and drug resistant isolates. *International Journal of Clinical Trials*, **3**(3):165-168.
- Kaya, O. (2024). Unveiling the transformations in phytochemicals and grape features: A thorough examination of 'Italia' and 'Bronx Seedless' cultivars throughout multiple berry development stages. *European Food Research and Technology*, **250**(8):2147-2160.
- Kowalczyk, T.; Muska'a, M.; Merez-Sadowska, A.; Sikora, J.; Picot, L. and Sitarek, P. (2024). Anti-inflammatory and anticancer effects of anthocyanins in *in vitro* and *in vivo* studies. *Antioxidants*, **13**(9):1143. <https://doi.org/10.3390/antiox13091143>.
- Kunter, B.; Unal, O. B.; Keskin, S.; Hatterman-Valenti, H. and Kaya, O. (2024). Comparison of the sugar and organic acid components of seventeen table grape varieties produced in Ankara: A study over two consecutive seasons. *Frontiers in Plant Science*, **15**:1321210.
- Lu, H. C.; Chen, W. K.; Wang, Y.; Bai, X. J.; Cheng, G.; Duan, C. Q.; Wang, J. and He, F. (2021). Effect of the seasonal climatic variations on the flavonoid accumulation in *Vitis vinifera* cv. 'Muscat Hamburg' and 'Victoria' grapes under the double cropping system. *Foods*, **11**. <https://doi.org/10.3390/foods11010048>.
- Mazur, A.; Bayle, D.; Lab, C.; Rock, E. and Rayssiguier, Y. (1999). Inhibitory effect of procyanidin rich extracts on LDL oxidation *in vitro*. *Atherosclerosis*, **145**(2):421-422. [https://doi.org/10.1016/s0021-9150\(99\)00115-x](https://doi.org/10.1016/s0021-9150(99)00115-x).
- McRae, J. M. and Kennedy, J. A. (2011). Wine and grape tannin interactions with salivary proteins and their impact on astringency: A review of current research. *Molecules*, **16**(3):2348-2364. <https://doi.org/10.3390/molecules16032348>.
- Miao, Y.; Wang, H.; Xu, X.; Ye, P.; Wu, H.; Zhao, R.; Shi, X. and Cai, F. (2022). Chemical and sensory characteristics of different red grapes Grown in Xinjiang, China: Insights into wines composition. *Fermentation*, **8**(12):689. <https://doi.org/10.3390/fermentation8120689>.
- Mota, A.; Pinto, J.; Fartouce, I.; Correia, M. J.; Costa, R.; Carvalho, R. and Oliveira, A. A. (2018). Chemical profile and antioxidant potential of four table grape (*Vitis vinifera*) cultivars grown in Douro region, Portugal. *Ciência e Técnica Vitivinícola*, **33**(2):125-135.
- Ndiaye, M.; Philippe, C.; Mukhtar, H. and Ahmad, N. (2011). The grape antioxidant resveratrol for skin disorders: Promise, prospects, and challenges. *Archives of Biochemistry and Biophysics*, **508**(2):164-170. <https://doi.org/10.1016/j.abb.2010.12.030>.
- Nirmala, J. G. and Narendhirakannan, R. T. (2011). *In vitro* antioxidant and antimicrobial activities of grapes (*Vitis vinifera* L.) seed and skin extracts of Muscat variety. *International Journal of Pharmacological Science*, **3**(4):242-249.
- Ogwu, M. C.; Izah, S. C. and Joshua, M. T. (2025). Ecological and environmental determinants of phytochemical variability in forest trees. *Phytochemistry Reviews*. <https://doi.org/10.1007/s11101-025-10066-0>.
- Paiva, A.; Claudio, A. F. and Ventura, S. P. (2023). Natural deep eutectic solvents: Emerging solvents for bioactive compound extraction. *Journal of Cleaner Production*, **412**:137926. <https://doi.org/10.1016/j.jclepro.2023.137926>.
- Parker, M.; Capone, D. L.; Francis, I. L. and Herderich, M. J. (2018). Aroma precursors in grapes and wine: Flavor release during wine production and consumption. *Journal of Agricultural and Food Chemistry*, **66**(10):2281-2286. <https://doi.org/10.1021/acs.jafc.6b05255>.

- Pascual, O.; González-Royo, E.; Gil, M.; Gómez-Alonso, S.; García-Romero, E.; Canals, J. M. and Zamora, F. (2020). Influence of grape maturity on the foaming properties of base wines and sparkling wines (Cava). *Food Chemistry*, **307**:125544. <https://doi.org/10.1016/j.foodchem.2019.125544>.
- RasinesPerea, Z. and Teissedre, P.L. (2017). Grape polyphenol effects in human cardiovascular diseases and diabetes. *Molecules*, **22**(1):68. <https://doi.org/10.3390/molecules22010068>
- Rauf, A.; Imran, M.; Butt, M. S.; Nadeem, M.; Peters, D. G. and Mubarak, M. S. (2023). Resveratrol as an anticancer agent: A review. *Critical Reviews in Food Science and Nutrition*, **58**(9):1428-1447. <https://doi.org/10.1080/10408398.2016.1263597>.
- Redondo, J. M.; Ruiz-Moreno, M. J.; Puertas, B.; Cuevas, F. J.; Carbu, M.; Moreno-Rojas, J. M. and Cantos-Villar, E. (2024). Impact of postharvest dehydration process on wine aroma compounds: A review. *Critical Reviews in Food Science and Nutrition*, **64**(1):1-15. <https://doi.org/10.1080/10408398.2022.2106932>.
- Rege, S. D.; Geetha, T.; Griffin, G. D.; Broderick, T. L. and Babu, J. R. (2014). Neuroprotective effects of resveratrol in Alzheimer disease pathology. *Frontiers in Aging Neuroscience*, **6**:218.
- Rio Segade, S.; Vilanova, M.; Giacosa, S.; Perrone, I.; Chitarra, W.; Pollon, M. and Rolle, L. (2017). Ozone improves the aromatic fingerprint of white grapes. *Scientific Reports*, **7**(1):16301.
- Rodriguez-Amaya, D. B.; Kimura, M. and Amaya-Farfan, J. (2022). Innovative extraction technologies for bioactive compounds. *Frontiers in Nutrition*, **9**:1008457. <https://doi.org/10.3389/fnut.2022.1008457>.
- Rogiers, S. Y.; Greer, D. H.; Liu, Y.; Baby, T. and Xiao, Z. (2022). Impact of climate change on grape berry ripening: An assessment of adaptation strategies for the Australian vineyard. *Frontiers in Plant Science*, **13**:1094633.
- Rogina, B. and Tissenbaum, H. A. (2024). SIRT1, resveratrol and ageing. *Frontiers in Genetics*, **15**:1393181. <https://doi.org/10.3389/fgene.2024.1393181>.
- Rudrapal, M.; Eltayeb, W. A.; Rakshit, G. and Sahoo, P. K. (2023). Dual synergistic inhibition of COX and LOX by potential chemicals from Indian daily spices investigated through detailed computational studies. *Scientific Reports*, **13**:8656. <https://doi.org/10.1038/s41598-023-35161-0>.
- Rudrapal, M.; Mishra, A. K.; Rani, L.; Sarwa, K. K.; Zothantluanga, J. H.; Khan, J.; Kamal, M.; Palai, S.; Bendale, A. R.; Talele, S. G.; Pathan, V. T.; Borse, L. B.; Neharkar, V. S. and Sahoo, P. K. (2022). Nanodelivery of dietary polyphenols for therapeutic applications. *Molecules*, **27**(24):8706. <https://doi.org/10.3390/molecules27248706>.
- Sabra, A.; Neticadan, T. and Wijekoon, C. (2021). Grape bioactive molecules, and the potential health benefits in reducing the risk of heart diseases. *Food Chemistry*, **12**:100149. <https://doi.org/10.1016/j.foodchem.2021.100149>.
- Salehi, B.; Mishra, A. P.; Nigam, M.; Sener, B.; Kilic, M.; Sharifi-Rad, M.; Fokou, P. V. T.; Martins, N. and Sharifi-Rad, J. (2018). Resveratrol: A double-edged sword in health benefits. *Biomedicines*, **6**(3):91. <https://doi.org/10.3390/biomedicines6030091>.
- Sanchez, M. C.; Romero, C.; Brenes, M.; Garcia, P. and Garrido, A. (2023). Kinetics of the hydrolysis of oleuropein in table olive brines. *Journal of Agricultural and Food Chemistry*, **71**(15):4563-4569. <https://doi.org/10.1021/jf030263u>.
- Sarkhosh-Khorasani, S. and Hosseinzadeh, M. (2021). The effect of grape products containing polyphenols on C-reactive protein levels: A systematic review and meta-analysis of randomized controlled trials. *The British Journal of Nutrition*, **125**(11):1230-1245. <https://doi.org/10.1017/S0007114520003591>.
- Sarkhosh-Khorasani, S.; Sangsefidi, Z. S. and Hosseinzadeh, M. (2021). The effect of grape products containing polyphenols on oxidative stress: a systematic review and meta analysis of randomized clinical trials. *Nutrition Journal*, **20**(1):25. <https://doi.org/10.1186/s12937-021-00686-5>.
- Satue-Gracia, M. T.; Heinonen, M. and Frankel, E. N. (1997). Anthocyanins as antioxidants on human low-density lipoprotein and lecithin³⁷ liposome systems. *Journal of Agricultural and Food Chemistry*, **45**(9):3362-3367.
- Schaefer, H. M.; Rentzsch, M. and Breuer, M. (2008). Anthocyanins reduce fungal growth in fruits. *Natural Product Communications*, **3**(8):193457-193458. <https://doi.org/10.1080/1522675080193457>.
- Segrestin, B.; Delage, P.; Nemeth, A.; Seyssel, K.; Disse, E.; Nazare, J. A. and Laville, M. (2022). Polyphenol supplementation did not affect insulin sensitivity and fat deposition during one-month overfeeding in randomized placebo controlled trials in men and in women. *Frontiers in Nutrition*, **9**:854255.
- Shen, Y.; Jin, L. and He, Y. (2021). Effects of different drying methods on the bioactive compounds and antioxidant activity of Muscat Hamburg grape pomace. *Food Chemistry*, **344**:128702.
- Shen, Y.; Zhang, N.; Tian, J.; Xin, G.; Liu, L.; Sun, X. and Li, B. (2022). Advanced approaches for improving bioavailability and controlled release of anthocyanins. *Journal of controlled release: Official journal of the Controlled Release Society*, **341**:285-299. <https://doi.org/10.1016/j.jconrel.2021.11.031>.
- Shimazu, R.; Anada, M.; Miyaguchi, A.; Nomi, Y. and Matsumoto, H. (2021). Evaluation of blood brain barrier permeability of polyphenols, anthocyanins, and their metabolites. *Journal of Agricultural and Food Chemistry*, **69**(39):11676-11686. <https://doi.org/10.1021/acs.jafc.1c02898>.
- Silva, L. R.; Pereira, M. J.; Azevedo, J.; Gonçalves, R. F.; Valentao, P.; de Pinho, P. G. and Andrade, P. B. (2022). *Glycine max* (L.) Merr., *Vitis vinifera* L. and *Citrus sinensis* L. leaves polyphenolic profile and biological activities. *Industrial Crops and Products*, **185**:115137. <https://doi.org/10.1016/j.indcrop.2022.115137>.
- Singh, G. and Pai, R. S. (2023). Optimized nanoemulsions for enhanced resveratrol delivery: Stability and bioavailability studies. *International Journal of Pharmaceutics*, **635**:122740. <https://doi.org/10.1016/j.ijpharm.2023.122740>.
- Smeriglio, A.; Barreca, D.; Bellocchio, E. and Trombetta, D. (2017). Proanthocyanidins and hydrolysable tannins: Occurrence, dietary intake and pharmacological effects. *British Journal of Pharmacology*, **174**(11):1244-1262.
- Smoliga, J. M. and Blanchard, O. (2023). Translating resveratrol from preclinical trials to clinical practice: A critical review of inconsistencies. *Pharmacological Research*, **188**:106663. <https://doi.org/10.1016/j.phrs.2023.106663>.
- Sodhi, G. K.; Kaur, G.; George, N.; Walia, H. K.; Sillu, D.; Rath, S. K. and Dwibedi, V. (2024). Waste to wealth: microbial-based valorization of grape pomace for nutraceutical, cosmetic, and therapeutic applications to promote circular economy. *Process Safety and Environmental Protection*, **185**:115137.
- Srivastava, R. A.; Pinkosky, S. L.; Filippov, S.; Hanselman, J. C.; Cramer, C. T. and Newton, R. S. (2012). AMP-activated protein kinase: an emerging drug target to regulate imbalances in lipid and carbohydrate metabolism to treat cardio-metabolic diseases. *Journal of Lipid Research*, **53**(12):2490-2514. <https://doi.org/10.1194/jlr.R025882>.
- Sun, Y.; Xi, B. and Dai, H. (2023). Effects of water stress on resveratrol accumulation and synthesis in 'Cabernet Sauvignon' grape berries. *Agronomy*, **13**(3):633. <https://doi.org/10.3390/agronomy13030633>.

- Tomasino, E. and Bolman, S. (2021).** The potential effect of ionone and damascenone on sensory perception of Pinot Noir wine aroma. *Molecules*, **26**(5):1288. <https://doi.org/10.3390/molecules26051288>.
- U.S. FDA (2022).** GRAS Notice for Resveratrol (GRN No. 997). <https://www.fda.gov>.
- Voloshyna, I.; Hussaini, S. M. and Reiss, A. B. (2012).** Resveratrol in cholesterol metabolism and atherosclerosis. *Journal of Medicinal Food*, **15**(9):763-773.
- Vujovic, D.; Maletic, R.; PopovicDordevic, J.; Pejin, B. and Ristic, R. (2017).** Viticultural and chemical characteristics of Muscat Hamburg preselected clones grown for table grapes. *Journal of the Science of Food and Agriculture*, **97**(2):587-594. <https://doi.org/10.1002/jsfa.7769>.
- Wang, L.; Sun, X. and Li, X. (2023).** Ultrasound-assisted enzymatic extraction of polyphenols from grape berries. *International Journal of Food Science and Technology*, **58**(7):2781-2793. <https://doi.org/10.1111/ijfs.16024>.
- Wang, X.; Xu, J. and Liu, Z. (2022).** Clinical potential of polyphenol-rich grapes: A review of human trials. *Journal of Nutritional Biochemistry*, **109**:109154.
- Winter, A. N. and Bickford, P. C. (2019).** Anthocyanins and their metabolites as therapeutic agents for neurodegenerative disease. *Antioxidants*, **8**(9):333. <https://doi.org/10.3390/antiox8090333>.
- Yadav, A.; Yadav, K.; Ahmad, R. and Abd-Elsalam, K. A. (2023).** Emerging frontiers in nanotechnology for precision agriculture: Advancements, hurdles and prospects. *Agrochemicals*, **2**(2):220-256. <https://doi.org/10.3390/agrochemicals2020016>.
- Yilmaz, F. and Gokeman, V. (2023).** Reduced-pressure extraction of polyphenols: A sustainable approach for plant-based bioactives. *Food Science and Nutrition*, **11**(4):4330-4345. <https://doi.org/10.1002/fsn3.4330>.
- Yinshan, G.; Zaozhu, N.; Kai, S.; Jia, Z.; Zhihua, R.; Yuhui, Z. and Xiuwu, G. (2017).** Composition and content analysis of sugars and organic acids for 45 grape cultivars from northeast region of China. *Pakistan Journal of Botany*, **49**(1):155-160.
- Youness, R. A.; Kamel, R.; Elkasabgy, N. A.; Shao, P. and Farag, M. A. (2021).** Recent advances in tannic acid (gallotannin) anticancer activities and drug delivery systems for efficacy improvement: A comprehensive review. *Molecules (Basel, Switzerland)*, **26**(5):1486. <https://doi.org/10.3390/molecules26051486>.
- Zagotta, I.; Dimova, E. Y.; Debatin, K. M.; Wabitsch, M.; Kietzmann, T. and Fischer-Posovszky, P. (2015).** Obesity and inflammation: Reduced cytokine expression due to resveratrol in a human *in vitro* model of inflamed adipose tissue. *Frontiers in Pharmacology*, **6**:79.
- Zhang, X.; Liu, J. and Wang, Y. (2024).** Enhancing Muscat Hamburg wine aroma through yeast strain selection: An innovative fermentation approach. *Foods*, **13**(11):1648. <https://doi.org/10.3390/foods13011648>.
- Zhang, Y. S.; Du, G.; Gao, Y. T.; Wang, L. W.; Meng, D.; Li, B. J.; Brennan, C.; Wang, M. Y.; Zhao, H.; Wang, S. Y. and Guan, W. Q. (2019).** The effect of carbonic maceration during winemaking on the color, aroma and sensory properties of 'Muscat Hamburg' wine. *Molecules (Basel, Switzerland)*, **24**(17):3120. <https://doi.org/10.3390/molecules24173120>.
- Zhao, D.; Simon, J. E. and Wu, Q. (2020).** A critical review on grape polyphenols for neuroprotection: Strategies to enhance bioefficacy. *Critical Reviews in Food Science and Nutrition*, **60**(4):597-625. <https://doi.org/10.1080/10408398.2018.1546668>.
- Zhu, L.; Huang, Y.; Zhang, Y.; Xu, C.; Lu, J. and Wang, Y. (2017).** The growing season impacts the accumulation and composition of flavonoids in grape skins in two-crop-a-year viticulture. *Journal of Food Science and Technology*, **54**(9):2861-2870. <https://doi.org/10.1007/s13197-017-2724-3>.
- Zunino S. (2009).** Type 2 diabetes and glycemic response to grapes or grape products. *The Journal of Nutrition*, **139**(9):1794S-800S. <https://doi.org/10.3945/jn.109.107631>.

Citation

R. Sneha, V. Jegadeeswari, K. R. Vijayalatha, R. K. Kaleeswari, S. Nithila and I. Muthuvel (2025). From vineyard to remedy: Medicinal attributes of Muscat Hamburg grapes. *Ann. Phytomed.*, **14**(1):528-538. <http://dx.doi.org/10.54085/ap.2025.14.1.50>.