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Grape Pomace as a Reliable Source of Phenolic Compounds: Polyphenol Composition and Biological Properties

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Abstract

Grape pomace, the residue from winemaking, has emerged as a promising source of phenolic compounds with diverse biological activities. This review explores the polyphenol composition of grape pomace and its potential health benefits. Grape pomace contains a variety of polyphenols, including flavonoids (such as anthocyanins, flavonols, and flavan-3-ols) and non-flavonoids (such as phenolic acids and stilbenes), which contribute to its antioxidant, anti-inflammatory, antimicrobial, cardioprotective, and anticancer properties. The extraction methods and analytical techniques used to quantify these polyphenols are discussed, highlighting the variability in polyphenol content based on grape variety, winemaking process, and extraction methods. Applications of grape pomace polyphenols in functional foods, nutraceuticals, cosmetics, and pharmaceuticals are reviewed, emphasizing their potential as sustainable ingredients. Moreover, the review addresses the challenges and prospects for utilizing grape pomace as a valuable source of bioactive compounds, promoting both environmental sustainability and economic viability in the wine industry.

Keywords: Phenolic compounds; Flavonoids; Polyphenols; Bioactive compounds

1 Introduction

Grape pomace, the solid residue remaining after grape juice or wine production, has emerged as a significant source of phenolic compounds, particularly polyphenols, known for their potent antioxidant properties. The botanical name of the common grape pomace or grapevine is Vitis vinifera. Comprised of grape skins, seeds, and stems, grape pomace is often considered a waste product. However, recent studies have demonstrated its potential as a valuable resource for extracting bioactive compounds that can be utilized in various industries, including food, pharmaceuticals, and cosmetics[1].

Polyphenols, the primary class of phenolic compounds found in grape pomace, are renowned for their diverse biological activities, including antioxidant, anti-

inflammatory, and antimicrobial properties. These compounds play a crucial role in human health, contributing to the prevention of chronic diseases such as cardiovascular diseases, cancer, and neurodegenerative disorders[2]. The characteristics of grapes used in grape pomace and the polyphenol composition of grape pomace extract can vary based on the grape variety, cultivation conditions, and processing methods, making it a complex but rich source of these valuable compounds[3].

This review aims to provide a comprehensive overview of the polyphenol composition of grape pomace, examining the factors influencing its phenolic content and the methods used for extraction and quantification. Additionally, it will explore the biological properties of these polyphenols and their potential applications in various fields. By highlighting the reliability of grape pomace as a source of phenolic compounds, this article seeks to underscore its significance in promoting health and sustainability.

1.1 Overview of Grape Pomace Composition

The composition of pomace of grapes as a waste product is highly dependent on waste type, grape variety, planting environment, processing method, and a range of other factors[4]. While red wine is formed by fermenting the entire grape mass, rose and white wines are prepared by fermenting the juice. All of this results in a wide range of grape pomace compositions. Grape pomace is the byproduct of pressing entire grapes during the must-making process. Grape pomace accounts for around 20-25% of total processed grape mass[5–8]. According to the analysis, 1 kilogram of grape pomace is produced for every 6 L of wine[9]. One kilogram of grape pomace contains 425 gm of grape skin, 225 gm of grape seeds, 250 gm of stalks, and other minor ingredients (for example, water), (Figure 1).

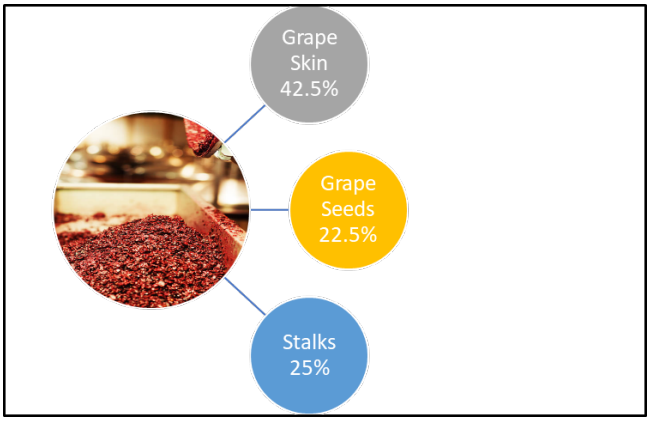

Fig 1. Overview of the composition of grape pomace

The exact composition of grape pomace acquired from research that includes a study of several red and white grape pomaces is shown in Table 1 [10].

Table 1. Details of the composition of grape pomace

Sr. No.	Name of Compounds	Quantity g/100gm
A. Physicochemical Parameters		
1	Ash	1.73
2	Protein	3.57
3	Fat	1.14
4	Total Dietary Fiber	17.28
5	Insoluble Fiber	16.44
6	Soluble Fiber	0.72
7	Carbohydrates	12.20
8	Total Phenolic Contents	0.28
9	Fructose	0.38
10	Glucose	0.21
B. Mineral Substances		
Sr. No.	**Name of Compounds**	**Quantity mg/100gm**
1	Na	87
2	K	1184
3	Mg	92
4	Ca	91
5	Mn	6
6	Fe	5
7	Zn	2
8	Cu	39
9	P	4

1.2 Grape Skin Structure and Composition

Grape skins, an integral part of grape pomace, play a vital role in determining the quality and characteristics of grape-derived products such as wine and juice. The structure and composition of grape skins are complex and diverse, encompassing a variety of bioactive compounds that contribute to the nutritional and sensory properties of these products.

1.2.1 Structure of Grape Skins

Grape skins consist of several layers that vary in thickness and composition among different grape varieties. The primary structural components include:

- **Cuticle:** The outermost layer, composed mainly of cutin, waxes, and other lipids, provides a protective barrier against environmental stressors and pathogens.
- **Epidermis:** Beneath the cuticle, the epidermis contains cells that store anthocyanins, which are responsible for the red, blue, or purple pigmentation in grape skins. These pigments are crucial for grape-derived products' visual appeal and antioxidant properties.

- **Hypodermis and Mesocarp:** These layers are rich in parenchyma cells and contain significant amounts of polysaccharides, particularly pectins, and cellulose, which contribute to the texture and structural integrity of the grape skin[11].

1.2.2 ***Composition of Grape Skins***

The biochemical composition of grape skins includes a variety of compounds that are beneficial for health and play a role in the winemaking process. Key components include:

- **Polyphenols:** Grape skins are a rich source of polyphenolic compounds, including flavonoids (anthocyanins, flavonols, flavan-3-ols) and non-flavonoids (phenolic acids, stilbenes). These compounds exhibit potent antioxidant, anti-inflammatory, and antimicrobial properties[12].
- **Tannins:** Present in significant amounts, tannins contribute to the astringency and mouthfeel of wines. They interact with proteins and polysaccharides during the winemaking process, affecting the stability and aging potential of wine.
- **Aromatic Compounds:** Grape skins contain various volatile compounds that contribute to the aroma and flavor profile of wines and juices. Terpenes, aldehydes, and esters are among the key aromatic compounds found in grape skins[13].
- **Dietary Fiber:** High in insoluble dietary fiber, grape skins promote digestive health and can be utilized in functional food products to enhance their nutritional value[14].

1.3 Grape Seed Structure and Composition

Grape seeds, an integral component of grape pomace, have garnered significant attention due to their rich nutritional profile and potential health benefits. Understanding the structure and composition of grape seeds is crucial for optimizing their use in various applications, such as dietary supplements, functional foods, and cosmetics.

1.3.1 ***Structure of Grape Seeds***

Grape seeds are small, hard structures located within the grape berry. They consist of several distinct layers:

- **Seed Coat (Testa):** The outermost layer, providing a protective barrier for the seed. It is composed of lignified cells that contribute to the seed's hardness and resistance to environmental stress.
- **Endosperm:** Located beneath the seed coat, the endosperm is a nutritive tissue that surrounds the embryo. It is rich in storage proteins and lipids, which provide essential nutrients for the developing plant.
- **Embryo:** The innermost part of the seed, consisting of the embryonic plant. The embryo contains the cotyledons (seed leaves), radicle (future root), and plumule (future shoot).

1.3.2 ***Composition of Grape Seeds***

Grape seeds are a rich source of bioactive compounds that contribute to their health-promoting properties. Key components include:

- **Polyphenols:** Grape seeds contain high concentrations of polyphenolic compounds, particularly proanthocyanidins, flavonoids, and phenolic acids. These compounds exhibit potent antioxidant, anti-inflammatory, and anticancer properties[15]. Proanthocyanidins, also known as condensed tannins, are the most abundant polyphenols in grape seeds and are recognized for their cardiovascular benefits and ability to neutralize free radicals.
- **Lipids:** Grape seed oil, extracted from the seeds, is rich in essential fatty acids, particularly linoleic acid (omega-6) and oleic acid (omega-9). These fatty acids are crucial for maintaining healthy cell membranes and supporting cardiovascular health[16].
- **Proteins:** Grape seeds contain a significant number of proteins, including albumins, globulins, and glutelins. These proteins can be hydrolyzed to produce bioactive peptides with potential health benefits, such as antihypertensive and antioxidant activities[17].
- **Dietary Fiber:** The high fiber content in grape seeds, primarily insoluble fiber, promotes digestive health by enhancing bowel movements and supporting gut microbiota[18].

1.4 Grape Inflorescence Architecture: Structure and Composition

Grape inflorescences, the flower clusters that eventually develop into grape berries, play a crucial role in determining the yield and quality of grape production. Understanding the structure and composition of grape inflorescences is essential for viticulture practices, breeding programs, and improving grapevine productivity.

1.4.1 ***Structure of Grape Inflorescences***

The architecture of grape inflorescences is complex, consisting of several key components:

- **Rachis:** The main axis or central stem of the inflorescence. It supports the lateral branches and is crucial for the transport of nutrients and water to the developing flowers and berries.
- **Peduncle:** The stalk that attaches the inflorescence to the grapevine. It provides structural support and serves as the conduit for nutrient and water flow from the vine to the inflorescence.

- **Pedicels:** The small stalks that connect individual flowers to the rachis or lateral branches. Each flower or berry is attached to the pedicel.
- **Flowers:** Grape flowers are small and typically green. They are arranged in clusters called cymes or panicles, depending on the grape variety. Each flower contains male and female reproductive organs, although some grapevine species may have unisexual flowers[19].

1.4.2 ***Composition of Grape Inflorescences***

Grape inflorescences contain a variety of compounds that are important for the development of flowers and subsequent berry formation. Key components include:

- **Floral Volatiles:** These are aromatic compounds emitted by grape flowers, playing a vital role in attracting pollinators and facilitating fertilization. Common floral volatiles include terpenes, esters, and aldehydes[20].
- **Hormones:** Plant hormones, such as auxins, gibberellins, cytokinins, and ethylene, regulate the growth and development of grape inflorescences. These hormones influence processes like flower initiation, differentiation, and fruit set[21].
- **Nutrients:** Essential nutrients, including nitrogen, phosphorus, potassium, and micronutrients, are critical for the healthy development of inflorescences. These nutrients are transported through the rachis and pedicels to the flowers.
- **Polyphenols:** Like other parts of the grapevine, inflorescences contain polyphenolic compounds that have antioxidant properties and contribute to the defense mechanisms against pathogens and environmental stressors[22].

1.5 Grape Pomace: The Main Winemaking By-product

Grape pomace, the primary by-product of the winemaking process, represents a substantial portion of the solid waste generated during wine production. This by-product, comprising grape skins, seeds, stems, and pulp, has traditionally been regarded as waste. However, its rich composition of bioactive compounds has garnered increasing interest for its potential applications across various industries.

1.6 Major grape pomace components[23]

Grape pomace components available in large quantity are mentioned in the Figure 2.

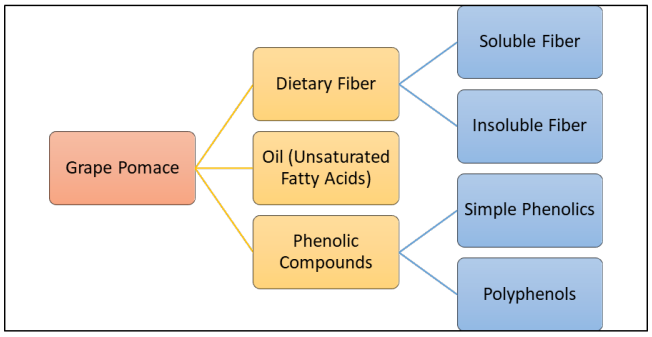

Fig 2. Major grape pomace components

1.7 Methods Used for the Extraction of Grape Pomace

The extraction of bioactive compounds from grape pomace is crucial for utilizing its nutritional and functional properties in various industries. Several extraction techniques are employed to efficiently recover polyphenols, lipids, proteins, and other valuable components from grape pomace.

1.7.1 ***Common Extraction Methods***

- **Solvent Extraction:**
  - **Description:** Solvent extraction is a widely used method to recover polyphenolic compounds from grape pomace. Common solvents include ethanol, methanol, and water, or their mixtures. The choice of solvent depends on the polarity of the target compounds.
  - **Process:** Grape pomace is typically ground or powdered and then mixed with the selected solvent. The mixture is then stirred, sonicated, or subjected to other agitation techniques to facilitate extraction. After extraction, the solvent is evaporated under reduced pressure, leaving behind a concentrated extract.
  - **Advantages:** Solvent extraction is versatile and can be optimized for specific compounds of interest. It allows for high extraction efficiency and is suitable for both small-scale and large-scale applications[24].
- **Supercritical Fluid Extraction (SFE):**
  - **Description:** SFE utilizes supercritical fluids, such as carbon dioxide (CO_2), to extract bioactive compounds from grape pomace. Supercritical CO_2 acts as both a solvent and a carrier for extracting non-polar and semi-polar compounds.
  - **Process:** Grape pomace is placed in an extraction vessel where CO_2 is heated and pressurized above its critical point, becoming a supercritical fluid. The supercritical CO_2 extracts the compounds from the pomace, and upon depressurization, the extracted compounds are collected.
  - **Advantages:** SFE is a green extraction method as CO_2 is non-toxic, non-flammable, and easily removed post-extraction. It produces high-quality extracts with minimal degradation of heat-sensitive

compounds[25].

- **Ultrasound-Assisted Extraction (UAE):**
  - **Description:** UAE uses ultrasonic waves to enhance the extraction efficiency of bioactive compounds from grape pomace. The mechanical energy generated by ultrasound disrupts cell walls and increases mass transfer rates, improving extraction yields.
  - **Process:** Grape pomace is mixed with a solvent in an extraction vessel, and ultrasound waves are applied. The cavitation effect created by ultrasound disrupts the cell structure, facilitating the release of polyphenols and other compounds into the solvent.
  - **Advantages:** UAE is a rapid and efficient method that reduces extraction time and solvent consumption compared to conventional methods. It enhances the extraction of heat-sensitive compounds and can be easily scaled up[26].
- **Pressurized Liquid Extraction (PLE):**
  - **Description:** PLE, also known as accelerated solvent extraction (ASE), uses elevated temperatures and pressures to enhance the extraction efficiency of polyphenols.
  - **Process:** Grape pomace is placed in an extraction cell with a solvent. The cell is pressurized and heated, which accelerates the extraction process. Polyphenols are extracted into the solvent phase.
  - **Advantages:** Shorter extraction times compared to conventional methods, higher extraction yields, and reduced solvent consumption[27].
- **Microwave-Assisted Extraction (MAE):**
  - **Description:** MAE uses microwave radiation (300 MHz to 300 GHz) to generate heat within the grape pomace, enhancing the release of bioactive compounds into the extraction solvent.
  - **Process:** Grape pomace and solvent are placed in a microwave reactor where electromagnetic waves heat the sample rapidly and uniformly, improving extraction efficiency.
  - **Advantages:** Rapid extraction process, reduced solvent consumption, and improved extraction yields for thermally stable compounds[28].
- **Enzyme-Assisted Extraction (EAE):**
  - **Description:** EAE utilizes enzymes (such as cellulase, pectinase, and protease) to break down cell walls and release intracellular compounds from grape pomace.
  - **Process:** Pomace is treated with enzymes under controlled conditions (pH, temperature) to enhance the accessibility of bioactive compounds to the extraction solvent.
  - **Advantages:** Specific enzymatic activity improves selectivity and efficiency in releasing target compounds, particularly polysaccharides and proteins[29].
- **Key compounds recovered from winemaking by-products[30] :**

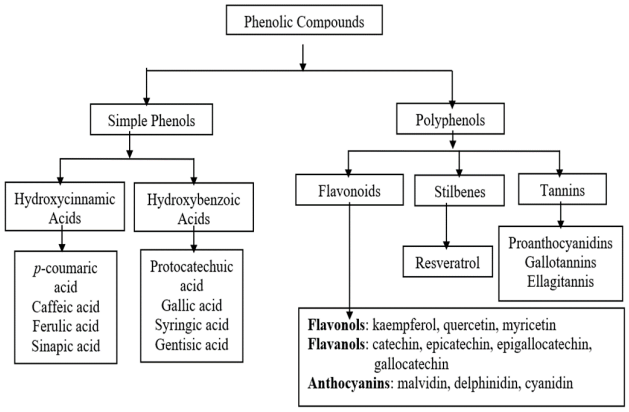

Fig 3. Phenolic compounds recovered from winemaking by-products

1.8 Methods for the Quantification of Grape Pomace

Quantifying grape pomace involves assessing various components such as polyphenols, dietary fiber, lipids, proteins, and other bioactive compounds. Several analytical methods are employed to determine the composition and characteristics of grape pomace, facilitating its utilization in various industries. Here are some commonly used methods:

1.8.1 *Total Phenolic Content (TPC)*

- **Folin-Ciocalteu Assay:** This colorimetric assay measures the reducing capacity of polyphenols in grape pomace extracts. It involves reacting the phenolic compounds with the Folin-Ciocalteu reagent, followed by spectrophotometric measurement at a specific wavelength[31].
- **HPLC (High-Performance Liquid Chromatography):** HPLC separates and quantifies individual polyphenolic compounds based on their retention times and characteristic absorbance spectra. It provides detailed information about the types and concentrations of polyphenols present in grape pomace.

1.8.2 *Antioxidant Capacity*

- **DPPH (2,2-Diphenyl-1-picrylhydrazyl) Assay:** This spectrophotometric assay measures the scavenging ability of antioxidants in grape pomace extracts against the

stable free radical DPPH. The decrease in absorbance indicates the antioxidant capacity of the sample[32].

- **FRAP (Ferric Reducing Antioxidant Power) Assay:** The FRAP assay quantifies the reducing ability of antioxidants by measuring the reduction of ferric (Fe^{3+}) to ferrous (Fe^{2+}) ions. It provides an overall measure of the antioxidant capacity of grape pomace extracts[33].

1.8.3 *Dietary Fiber Content*

- **Gravimetric Method (AOAC 985.29):** This method involves enzymatic digestion and gravimetric determination of total dietary fiber in grape pomace. It quantifies both soluble and insoluble dietary fiber components.
- **Englyst Method:** This method categorizes dietary fiber into fractions (soluble, insoluble, and resistant starch) using a series of enzymatic digestions and gravimetric measurements. It provides detailed information about the fiber composition in grape pomace[34].

1.8.4 *Lipid Content*

- **Soxhlet Extraction:** Soxhlet extraction is used to determine the lipid content in grape pomace. It involves continuous extraction using organic solvents (e.g., hexane) followed by solvent evaporation and gravimetric measurement of the lipid extract.
- **Gas Chromatography (GC):** GC separates and quantifies individual fatty acids in the lipid extract of grape pomace. It provides information about the composition and concentration of different lipid components[35].

1.8.5 *Protein Content*

- **Kjeldahl Method:** The Kjeldahl method determines the total nitrogen content in grape pomace, which is then used to calculate the protein content. It involves digestion with sulfuric acid, distillation, and titration to determine the nitrogen content.
- **Biuret Method:** This colorimetric method measures protein concentration based on the formation of a blue complex between proteins and copper ions under alkaline conditions. It provides a rapid assessment of protein content in grape pomace extracts[36].

1.8.6 *Other Bioactive Compounds*

- **HPLC-MS (High-Performance Liquid Chromatography-Mass Spectrometry):** HPLC-MS is used to identify and quantify a wide range of bioactive compounds in grape pomace, including vitamins, flavonoids, and organic acids. It combines the separation power of HPLC with the detection capabilities of mass spectrometry[37].
- **ELISA (Enzyme-Linked Immunosorbent Assay):** ELISA assays are used to quantify specific bioactive compounds or antigens in grape pomace extracts. They provide sensitive and specific detection of target molecules, such as allergens or specific phenolic compounds[38].

These methods offer a comprehensive approach to quantifying and characterizing the composition of grape pomace, facilitating its utilization in various industrial applications, and contributing to sustainable practices in the wine industry.

1.9 Biological Properties of Grape Pomace Polyphenols

Grape pomace, the by-product of winemaking, is a rich source of polyphenolic compounds known for their potent biological properties and diverse applications. The polyphenols extracted from grape pomace include flavonoids, phenolic acids, and tannins, which exhibit a range of health benefits and functional uses in various industries.

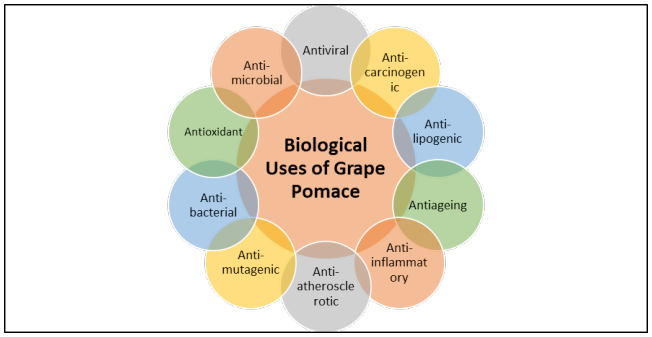

Fig 4. Biological uses of Grape Pomace Polyphenols[39]

- **Antioxidant Activity:** Grape pomace polyphenols are potent antioxidants that neutralize free radicals and prevent oxidative stress, which is implicated in aging and various chronic diseases. The antioxidant capacity of these polyphenols is attributed to their ability to donate hydrogen atoms and their metal-chelating properties[40].
- **Anti-inflammatory Effects:** Polyphenols in grape pomace have been shown to reduce inflammation by inhibiting the production of pro-inflammatory cytokines and enzymes such as cyclooxygenase (COX) and lipoxygenase (LOX). This anti-inflammatory activity is beneficial in preventing and managing inflammatory conditions such as arthritis and cardiovascular diseases[41].
- **Antimicrobial Properties:** The antimicrobial activity of grape pomace polyphenols is effective against a range of pathogens, including bacteria, fungi, and viruses. These polyphenols disrupt microbial cell membranes, inhibit

enzyme activity, and interfere with microbial DNA synthesis, making them useful in food preservation and the development of antimicrobial products[42].

- **Cardioprotective Effects:** Regular consumption of grape pomace polyphenols has been linked to improved cardiovascular health. These polyphenols help reduce blood pressure and decrease LDL cholesterol levels while increasing HDL cholesterol. They also inhibit platelet aggregation, reducing the risk of thrombosis[43].
- **Anticancer Activity:** Grape pomace polyphenols exhibit anticancer properties by inducing apoptosis, inhibiting cell proliferation, and preventing metastasis in various cancer cell lines. They modulate signaling pathways involved in cancer development, such as the PI3K/Akt and MAPK pathways, and enhance the efficacy of conventional chemotherapy[44].

1.10 Applications of Grape Pomace Polyphenols

The diverse composition of grape pomace allows for its use in several applications:

- **Animal Feed:** Grape pomace is often used as a feed supplement for livestock due to its high fiber and nutrient content. It can enhance the nutritional profile of animal diets and improve overall health[45].
- **Composting and Soil Amendment:** When composted, grape pomace serves as an excellent organic fertilizer, enriching soil with essential nutrients and improving soil structure[46].
- **Extraction of Bioactive Compounds:** The polyphenols and antioxidants extracted from grape pomace are used in the food, cosmetic, and pharmaceutical industries. These compounds are valued for their health-promoting properties, including anti-inflammatory, anti-cancer, and cardiovascular benefits[47].
- **Bioenergy Production:** Grape pomace can be used to produce biofuels such as biogas and ethanol through fermentation processes, contributing to sustainable energy solutions[48].
- **Functional Foods and Beverages:** Grape pomace polyphenols are added to functional foods and beverages to enhance their nutritional profile and provide health benefits. These polyphenols improve the antioxidant capacity of the products, contributing to overall health and wellness.
- **Nutraceuticals and Dietary Supplements:** Due to their potent bioactive properties, grape pomace polyphenols are formulated into nutraceuticals and dietary supplements. These products are marketed for their antioxidant, anti-inflammatory, and cardioprotective effects, supporting various aspects of health[49].
- **Cosmetics and Personal Care Products:** The antioxidant and anti-inflammatory properties of grape pomace polyphenols make them valuable ingredients in cosmetics and personal care products. They protect the skin from oxidative damage, reduce inflammation, and promote skin health, making them popular in anti-aging and skincare formulations[50].
- **Food Preservation:** Grape pomace polyphenols are used as natural preservatives in the food industry due to their antimicrobial properties. They extend the shelf life of food products by inhibiting the growth of spoilage microorganisms and pathogens, ensuring food safety and quality[51].
- **Pharmaceutical Applications:** The therapeutic potential of grape pomace polyphenols is explored in the development of pharmaceutical products. Their anticancer, cardioprotective, and anti-inflammatory properties are harnessed to create medications that can prevent and treat various diseases[52].

1.11 Environmental and Economic Impact

Utilizing grape pomace has significant environmental and economic benefits:

- **Waste Reduction:** By repurposing grape pomace, the volume of waste generated by the wine industry is significantly reduced, alleviating disposal issues and environmental impact.
- **Economic Value:** The transformation of grape pomace into valuable products can create additional revenue streams for wineries, promoting economic sustainability[53].

2 Conclusion

Grape pomace once considered a by-product of winemaking, has evolved into a valuable reservoir of polyphenolic compounds with significant biological activities. This review has highlighted the diverse polyphenol composition of grape pomace, encompassing flavonoids, phenolic acids, and stilbenes, which contribute to its antioxidant, anti-inflammatory, antimicrobial, cardioprotective, and anticancer properties. The extraction methods and analytical techniques discussed underscore the variability in polyphenol content across grape varieties, winemaking processes, and extraction methodologies, influencing the bioactivity and potential applications of grape pomace extracts.

The applications of grape pomace polyphenols in functional foods, nutraceuticals, cosmetics, and pharmaceuticals demonstrate their versatility and commercial potential. By integrating grape pomace into these products, industries can harness its bioactive potential while promoting sustainable practices within the wine industry. Furthermore, the utilization of grape pomace not only reduces environmental impact

by valorizing waste but also creates economic opportunities through the development of high-value products. Future research should focus on optimizing extraction techniques, elucidating mechanisms of action, and exploring novel applications to enhance the value and efficacy of grape pomace-derived products.

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