vinetur

REPORT

The Grape Berry (*Vitis vinifera*): A Comprehensive Analysis of Its Anatomy, Composition, and Significance

2025-07-04

Introduction

The grape berry, the fruit of the genus *Vitis*, stands as a subject of profound botanical, agricultural, and economic importance. While colloquially recognized as a simple fruit, a more rigorous scientific examination reveals it to be a complex and dynamic biochemical system. Botanically, the grape is classified as a true berry, a fleshy fruit that develops from the ripened ovary of a flowering plant following fertilization.[1] Its defining characteristic is a pericarp—the ovary wall—that differentiates into the fleshy, edible tissue surrounding the seeds.[2] This seemingly straightforward structure belies an intricate compartmentalization of chemical compounds, the precise location and evolution of which dictate the quality, character, and ultimate value of grape-derived products.

The global significance of the grape is inextricably linked to its millennia-long use in the production of wine, a beverage of immense cultural and economic weight. Beyond oenology, grapes are consumed fresh as table grapes and processed into juice, raisins, and vinegar.[4] Furthermore, the byproducts of the winemaking industry, particularly the seeds and skins, have emerged as a source of high-value extracts for the nutraceutical, cosmetic, and food industries, representing a modern valorization of what was once considered waste.[5]

This report provides an exhaustive examination of the grape berry's anatomical structures—the skin, pulp, and seeds—and the diverse panoply of chemical

compounds they contain. It will elucidate the intricate relationships between botanical form, biochemical function, and industrial application. By dissecting the berry's architecture and mapping the distribution of its constituent molecules, from simple sugars and acids to complex polyphenols and aromatic precursors, this analysis will demonstrate how the functional specialization of each tissue is the fundamental determinant of the sensory and chemical profile of all products derived from this remarkable fruit.

The Architecture and Development of the Grape Berry

To comprehend the chemical complexity of the grape, one must first understand its physical architecture, from the macroscopic structure of the cluster down to the cellular organization of the berry itself. This architecture is not static; it is the result of a dynamic developmental process that dictates the timing and location of biochemical synthesis and accumulation.

The Grape Cluster and Berry Anatomy

The individual grape berry is borne on a larger structure known as a cluster or bunch. The cluster consists of a main stalk, the **peduncle**, which connects to a central, branching axis called the **rachis**. From the rachis, smaller stems known as **pedicels** (or cap stems) attach to each berry.[7] The total weight of a grape cluster is highly dependent on the grape variety and vintage conditions, but the berries themselves consistently account for the vast majority of the mass, typically 92% to 97%.[7]

The grape berry is a simple fruit, meaning it develops from a single ovary of a single flower.[9] Anatomically, it is divided into three principal tissues: the

skin (exocarp), the **flesh or pulp (mesocarp)**, and the **seeds**.[7] Each of these parts possesses a distinct cellular structure and, consequently, a unique biochemical profile that defines its contribution to the whole.[10]

The Pericarp: A Functional Tri-Layer System

The skin and pulp are parts of the **pericarp**, which is the wall of the ripened ovary. The pericarp is anatomically differentiated into three layers: the exocarp, the mesocarp, and the endocarp.[1]

The Skin (Exocarp)

The skin, also referred to as the exocarp or epicarp, is the berry's protective outer layer.[2] It is a multi-layered tissue, typically composed of six to ten layers of thick-walled cells.[11] The outermost surface is coated with a waxy, hydrophobic layer called the

cuticle. This cuticle is often visible as a whitish, powdery film known as the **bloom** or *pruina*.[8] This bloom is not merely cosmetic; it serves as a waterproof barrier and can host a microflora of wild yeasts, including

Saccharomyces cerevisiae, which are capable of initiating spontaneous alcoholic fermentation.[8]

The physiology of the grape skin is unique among fruits. It contains very few, if any, functional stomata (pores for gas exchange).[3] This anatomical feature has profound consequences for the berry's interaction with its environment. The lack of stomata severely limits water loss through transpiration, which means the berry is inefficient at dissipating heat via evaporative cooling. This makes it highly susceptible to sunburn and heat stress, which can degrade sensitive pigments and aroma compounds. Furthermore, the waterproof nature of the cuticle means the berry cannot easily shed excess water taken up from the vine, for instance after a heavy rainfall. This can lead to a rapid increase in internal turgor pressure that exceeds the skin's elasticity, causing the berry to split.[12] This creates a persistent dilemma for viticulturists, who must balance the need for sun exposure to ripen flavor compounds against the risk of heat damage, and manage irrigation to prevent splitting.

Just beneath the outer epidermis lies the **hypodermis**, a layer of tightly packed, flattened cells.[12] This tissue is of paramount importance as it is the primary site for the synthesis and accumulation of many of the most critical phenolic compounds that

define wine quality, including tannins and, in red varieties, the anthocyanin pigments responsible for color.[7]

The Pulp (Mesocarp)

The pulp, or mesocarp, is the voluminous interior of the berry, constituting 75% to 85% of its total weight and serving as the source of the juice, or must.[7] It is composed primarily of large, spherical parenchyma cells with relatively thin cell walls.[1] The most notable feature of these cells is their massive central

vacuole, which expands dramatically during ripening to occupy as much as 99% of the total cell volume.[12] These vacuoles are the primary storage organelles for the berry's most abundant constituents: water, sugars (glucose and fructose), and organic acids (tartaric and malic acid).[12]

A network of vascular bundles permeates the pulp, branching out from the pedicel. These bundles contain both **xylem**, which transports water and minerals from the roots, and **phloem**, which transports sugars (in the form of sucrose) from the leaves.[14] The function of these vascular tissues changes dramatically during ripening and is a key regulator of the entire process.

The Endocarp

The endocarp is the innermost layer of the pericarp. In the grape berry, it is not a hard, stony layer as in drupes like peaches, but rather a thin, soft tissue composed of several cell layers that line the seed-bearing cavities, or carpels.[1] It forms the final boundary between the fleshy pulp and the seeds themselves.[2]

The Seed: The Germ of a New Generation

Embedded within the center of the pulp are the seeds. A grape berry typically contains between one and four seeds, although seedless varieties exist.[7] The seeds

are not passive inclusions; they are biologically active, producing plant growth regulators that influence the final size and development of the berry.[7] From a reproductive standpoint, each seed consists of a tough, protective outer

seed coat (which develops from the integuments of the ovule), a nutritive tissue called the **endosperm** that provides nourishment for early growth, and the diploid **embryo** (2n), which contains the genetic information for a new vine.[1] For the winemaker and food scientist, the seeds are of interest as a highly concentrated source of tannins and oils.[7]

The Dynamics of Berry Development

The growth of a grape berry is not linear but follows a characteristic **double sigmoid curve**, which is commonly described as three distinct developmental stages, or two principal growth periods separated by a lag phase.[10]

- **Stage I (First Growth Period):** Following flowering and fruit set, the berry enters a phase of rapid growth driven by both cell division and cell expansion. Cell division is most intense in the first two weeks after anthesis (flowering) and ceases entirely after 30 to 40 days.[10] During this stage, the berry is small, hard, and green due to the presence of chlorophyll. Its metabolism is focused on building structure and accumulating defensive compounds. It actively synthesizes and stores large quantities of tartaric and malic acids in its vacuoles, resulting in a very high acidity. It also accumulates tannins in the skin and seeds, which are highly bitter at this stage.[10] The final berry size is largely determined by the number of cells formed during this period.[10]
- **Stage II (Lag Phase):** Growth slows and may appear to stagnate for a period of one to several weeks. During this phase, the organic acid concentration within the berry reaches its maximum level.[10] Some researchers view this phase not as a distinct stage but as the terminal part of the first growth period.[10]
- **Stage III (Second Growth Period / Ripening):** This stage is initiated by the onset of ***véraison***, a French term for the beginning of ripening. *Véraison* marks a profound and coordinated shift in the berry's physiology and metabolism.[10] The berry begins to soften, chlorophyll in the skin is degraded, and in red varieties, the synthesis of red and purple anthocyanin pigments commences, causing the berry to change color.[14] The most dramatic metabolic change is the rapid accumulation of sugars (glucose and fructose) in the vacuoles, coupled with a decline in acid

concentration.[10] Growth resumes, but it is now driven exclusively by cell enlargement as the massive influx of sugar draws water into the cells, causing them to swell.[10]

This entire ripening cascade is triggered by a fundamental change in the berry's vascular system. Before *véraison*, the berry receives water and nutrients from both the xylem and phloem. At the onset of *véraison*, the xylem flow into the berry largely ceases, effectively isolating it hydraulically from the rest of the vine.[14] From this point forward, the phloem becomes the exclusive conduit for importing solutes, primarily sucrose.[14] This vascular shift is the master switch that flips the berry's metabolism from a structural growth mode to a sugar-accumulating "sink" mode, initiating all the subsequent changes associated with ripening.

The following table provides a concise summary of the grape berry's main anatomical parts and their primary chemical constituents.

Table 1: Anatomical and Compositional Summary of Grape Berry Parts

Part	Approximate % of Berry Weight	Key Anatomical Features	Primary Chemical Constituents
Skin (Exocarp)	10–20%	Waxy cuticle (bloom), hypodermal cell layers, few functional stomata.[7]	Anthocyanins (in red varieties), tannins (proanthocyanidins), flavonols, aroma compounds and precursors, minerals (potassium).[11]
Pulp (Mesocarp)	75–85%	Large parenchyma cells with massive central vacuoles, vascular bundles (xylem and phloem).[7]	Water, sugars (glucose, fructose), organic acids (tartaric, malic), nitrogenous compounds, minerals.[11]
Seeds	2–5%	Hard outer seed coat, endosperm (nutritive tissue), embryo.[7]	Tannins (proanthocyanidins), oils (lipids), proteins, fiber.[7]

The Chemical Composition of the Grape Pulp (Mesocarp)

The pulp, or mesocarp, is the engine of the grape berry, constituting the vast majority of its volume and serving as the reservoir for the primary components of grape juice: water, sugars, and acids. The precise balance of these compounds at harvest is the single most important determinant of must quality and the foundation upon which wine is built.

Water: The Universal Solvent

Water is the most abundant chemical compound in the grape pulp, typically accounting for 70% to 85% of the berry's total weight.[11] Its role is fundamental. It acts as the universal solvent in which all other soluble components—sugars, acids, minerals, and nitrogenous compounds—are dissolved, forming the cell sap or juice.[18] Beyond its role as a solvent, water is essential for maintaining the cellular turgor pressure that is the physical force driving the expansion of the berry during the ripening phase (Stage III).[12] The significant influx of water into the vacuoles post-

véraison is also responsible for the dilution of organic acids and tannins that are present in the flesh, contributing to the shift in the berry's taste profile from tart and astringent to sweet and palatable.[12]

Sugars: The Fuel for Fermentation

Following water, sugars are the most plentiful solids in the grape pulp, and their accumulation is the defining characteristic of ripening.[11] At harvest, they can comprise 15% to 25% of the berry's total composition.[24]

Glucose and Fructose

The principal sugars found in grapes are the two simple, six-carbon monosaccharides: **glucose** and **fructose**.[11] These sugars are not synthesized within the berry itself. Rather, they are the products of the enzymatic hydrolysis of

sucrose, a disaccharide that is produced in the leaves via photosynthesis and transported to the berry through the phloem vascular tissue.[24]

The ratio of glucose to fructose evolves dynamically throughout ripening. In the early, unripe stages, glucose is the predominant sugar. As ripening progresses through *véraison*, fructose begins to accumulate rapidly, eventually reaching a ratio of approximately 1:1 with glucose in a fully mature berry.[11] In overripe or late-harvest grapes, the concentration of fructose often surpasses that of glucose.[11] This ratio is significant for both sensory perception and fermentation. Fructose is considerably sweeter than glucose, with a relative sweetness of approximately 1.73 compared to 0.74 for glucose (where sucrose is defined as 1.0).[24] This means that musts with a higher fructose content will be perceived as sweeter. Furthermore, the primary wine yeast,

Saccharomyces cerevisiae, is glucophilic, meaning it metabolizes glucose more readily and rapidly than fructose.[25] This preferential consumption of glucose can lead to a must that is enriched in fructose toward the end of fermentation. Because fructose is more difficult for yeast to ferment, this imbalance is a common cause of "stuck" or sluggish fermentations and is why off-dry wines with residual sugar often taste sweeter than their total sugar concentration might suggest.[25]

Structural Polysaccharides

The cell walls of the mesocarp parenchyma cells provide structural integrity. These walls are composed of a complex matrix of polysaccharides. The most abundant of these are **cellulose** and **pectins** (including homogalacturonans and rhamnogalacturonans), which together can account for 30% to 40% each of the cell wall material, along with **hemicelluloses**.[28] During ripening, enzymatic degradation of the pectic substances that cement the cells together occurs. This process is responsible for the characteristic softening of the berry post-

véraison and is particularly pronounced in "slip-skin" grape varieties, like Concord,

where it allows the skin to separate readily from the pulp.[12] These polysaccharides can also be partially solubilized into the must during winemaking, where they contribute to the final viscosity and mouthfeel of the wine.

Organic Acids: The Foundation of Taste and Stability

After sugars, organic acids are the most abundant group of soluble solids in the pulp. They are critically important, providing the tart taste that balances the sweetness of the sugars and defining the juice's pH.[11] A low pH is essential for the chemical and microbial stability of wine, as it inhibits the growth of spoilage organisms and stabilizes the red color of anthocyanin pigments.[11]

Tartaric and Malic Acid

Two dicarboxylic acids, **L-tartaric acid** and **L-malic acid**, are the dominant organic acids in grapes, collectively accounting for over 90% of the total acidity.[11] Grapes are one of the very few fruits to accumulate significant quantities of tartaric acid, making it a chemical signature of the

Vitis genus.[11]

The concentrations of these two acids follow distinct trajectories during berry development. Both are synthesized and accumulate during the first growth stage (Stage I), causing the titratable acidity of the green berry to rise to its peak just before *véraison*.[16] After

véraison, the concentration of both acids begins to decline. This decline is partly due to a simple dilution effect as the berry swells with water and sugar.[12] However, a more significant factor is the differential metabolism of the two acids. Malic acid, an intermediate in the Krebs (or tricarboxylic acid) cycle, is actively consumed as a substrate for cellular respiration to provide energy for the ripening process.[15] In essence, the berry "breathes away" its malic acid. Tartaric acid, by contrast, is synthesized via a separate pathway from ascorbic acid and is not a primary respiratory substrate; it remains metabolically stable within the vacuole.[16]

This differential fate is a defining biochemical feature of grape ripening. It allows the fruit to selectively reduce its harsh, "green" malic acidity while retaining the more stable tartaric acid, which provides the essential structural acidity for wine balance, stability, and aging potential. Consequently, at harvest, the must of most *Vitis vinifera* varieties contains significantly more tartaric acid than malic acid.[11]

Minor Acids

In addition to the two major acids, grape pulp contains smaller quantities of other organic acids. **Citric acid** is consistently present, though at low concentrations.[11]

Succinic acid, another intermediate of the citric acid cycle, is also found in the berry.[32]

Nitrogenous Compounds and Minerals

The grape pulp contains a variety of nitrogen-containing compounds, including inorganic ammonium ions, and organic forms such as free amino acids, peptides, and proteins.[8] From a winemaking perspective, the free amino acids and ammonium are of paramount importance as they constitute the

Yeast Assimilable Nitrogen (YAN). YAN is an essential nutrient source for yeast, and insufficient levels in the must can lead to stressed fermentations, the production of off-aromas like hydrogen sulfide, and an increased risk of stuck fermentation.[8]

The pulp is also a repository for minerals absorbed from the soil and transported into the berry. Of these, **potassium (K+)** has the most significant impact on wine chemistry.[11] Potassium ions can displace a proton on a tartaric acid molecule, forming the salt

potassium bitartrate (KHT), also known as cream of tartar.[34] This reaction has two major consequences. First, it consumes a free hydrogen ion (H+), which causes the pH of the must to rise (become less acidic). Second, KHT is less soluble in ethanol and at cold temperatures than tartaric acid, and it will often precipitate out of solution during fermentation and aging.[34] This precipitation physically removes tartrate from

the wine, thereby lowering the total or titratable acidity (TA).

This dynamic creates a complex buffering system where pH and TA are not linearly related. High potassium levels in the vineyard can lead to grapes with a high pH, even when the TA appears adequate. This makes potassium a "hidden regulator" of acidity, and its management in the vineyard is a critical, though often overlooked, factor in achieving chemical stability in the final wine.

The following table summarizes the properties and ripening dynamics of the four most important sugar and acid compounds in the grape pulp.

Table 2: Major Organic Acids and Sugars in Grape Pulp: Properties and Ripening Dynamics

Compound	Chemical Family	Relative Sweetness/Acidity	Concentration Trend During Ripening	Key Functional Role
Glucose	Monosaccharide Sugar	Sweetness ~0.74 (Sucrose = 1.0).[24]	Increases dramatically after *véraison*.[25]	Primary energy source for yeast fermentation; contributes to sweetness.[24]
Fructose	Monosaccharide Sugar	Sweetness ~1.73 (Sucrose = 1.0).[24]	Increases dramatically after *véraison*, often exceeding glucose in overripe fruit.[24]	Contributes significantly to perceived sweetness; less preferred by yeast than glucose.[25]
Tartaric Acid	Dicarboxylic Acid	Stronger acid than malic acid.[34]	Accumulates pre-*véraison*; decreases post-*véraison* due to dilution but is metabolically stable.[16]	Provides stable, structural acidity; critical for wine pH, stability, and aging.[11]
Malic Acid	Dicarboxylic Acid	Weaker acid than tartaric	Accumulates pre-*véraison*;	Contributes to "green," tart

		acid.[34]	decreases sharply post-*véraison* due to dilution and metabolic respiration.[15]	acidity; its reduction is a key marker of ripeness.[15]

The Skin (Exocarp): A Nexus of Quality and Character

The grape skin is far more than a simple protective container. It is a chemically complex and metabolically active tissue that serves as the primary repository for the compounds that define a wine's most salient characteristics: its color, the majority of its aroma, and a significant portion of its texture and structure.

Phenolic Compounds: Architects of Sensory Experience

The skin, and more specifically the hypodermal cell layers just beneath the cuticle, is the principal location for the synthesis and storage of a diverse array of phenolic compounds.[7] These are secondary metabolites that, in the plant, serve functions related to defense against pathogens, protection from UV radiation, and attraction of seed-dispersing animals.[4] In wine, they are the architects of the sensory experience.

Anthocyanins (Pigments)

Anthocyanins are a class of flavonoid compounds that function as pigments, responsible for the vast spectrum of red, purple, and blue hues observed in red grape varieties.[12] With the exception of a few rare grape varieties known as

teinturiers (in which the pulp is also colored), anthocyanins are located exclusively within the vacuoles of the skin cells.[36]

Chemically, anthocyanins are glycosides, meaning they consist of a core pigment

molecule, an **anthocyanidin**, attached to one or more sugar molecules (typically glucose).[35] In

Vitis vinifera grapes, there are five principal anthocyanidins: **delphinidin, cyanidin, petunidin, peonidin, and malvidin**.[17] Of these, malvidin-3-O-glucoside is often the most abundant and is responsible for a deep red-purple color.[36] The base anthocyanins can be further modified through acylation, where an acyl group (like an acetyl or coumaroyl group) is attached to the sugar moiety. These modifications enhance the stability and can alter the hue of the pigment.[17]

The biosynthesis of anthocyanins does not occur until the onset of ripening at *véraison*.[15] The concentration and specific profile of anthocyanins produced are highly dependent on the grape variety, vintage conditions (temperature and sunlight), and viticultural practices.[17] Indeed, the anthocyanin profile is so genetically determined that it can be used as a chemotaxonomic marker to identify and classify different red grape varieties.[17]

The color expressed by anthocyanins is exquisitely sensitive to the pH of the surrounding medium. In the highly acidic environment of wine (typically pH 3.2-3.8), the dominant form is the red-colored flavylium cation. As the pH rises, the molecule undergoes structural changes, shifting to purple, blue, and eventually colorless forms.[36] This makes maintaining a low wine pH critical for color intensity and stability. Anthocyanins can also be temporarily bleached by the addition of sulfur dioxide (SO_2), a common winemaking preservative.[36]

Skin Tannins (Condensed Tannins/Proanthocyanidins)

Tannins are polymeric phenolic compounds responsible for the tactile sensations of **astringency** (a drying, puckering feeling in the mouth) and bitterness in wine.[12] Chemically, they are classified as

condensed tannins or **proanthocyanidins**, which are oligomers and polymers built from repeating subunits of flavan-3-ol monomers, such as catechin and epicatechin.[40]

Like anthocyanins, skin tannins are concentrated in the vacuoles of the hypodermal cells.[12] However, their developmental trajectory is markedly different. Tannins are synthesized and accumulate early in berry development, well before

véraison.[7] After

véraison, while the total amount of tannin per berry may not increase significantly, the chemical nature of these tannins undergoes a crucial evolution. This process, often referred to as "phenolic ripeness," involves the polymerization of smaller tannin molecules into larger ones and other structural modifications.[12] These changes are sensorially significant: larger, more polymerized tannins are perceived as less astringent and less bitter, contributing to a "smoother," "rounder," or "softer" mouthfeel in the resulting wine. The tannins found in the skin are structurally distinct from those in the seeds; they are generally larger (have a higher mean degree of polymerization) and are built from a different mix of monomers, including epigallocatechin, which contributes to their softer sensory profile.[40]

Flavonols

Flavonols are another important class of flavonoid compounds found in the grape skin. The most common flavonols in grapes include **quercetin, kaempferol, and myricetin**.[17] They function as yellow pigments and, more importantly, as a natural sunscreen for the berry. Their synthesis is directly stimulated by exposure to sunlight, and they accumulate in the skin cells to absorb and dissipate harmful ultraviolet (UV) radiation.[17]

In wine, flavonols play a critical role as **co-pigments**. They have a planar chemical structure that allows them to associate with and stack between anthocyanin molecules in a process called co-pigmentation. This molecular association has two beneficial effects: it protects the anthocyanin from degradation, thereby stabilizing the wine's color, and it can shift the perceived color to a more intense, bluish-red hue.[36]

The Aromatic Profile: Volatiles and Their Precursors

The vast majority of a grape's characteristic aroma compounds, as well as their non-volatile precursors, are concentrated in the skin and the cell layers immediately beneath it.[11] The final aroma of a wine is a complex mosaic derived from these

grape-derived compounds, modified and supplemented by compounds produced by yeast during fermentation.

Key Aroma Families

Several major chemical families of volatile compounds contribute to the primary, or "varietal," aroma of grapes:

- **Monoterpenes:** Compounds like linalool, geraniol, and nerol are responsible for the intense floral (rose, orange blossom) and fruity (grape) aromas that are the hallmark of aromatic varieties such as Muscat, Gewürztraminer, and Riesling.[12]
- **C13-Norisoprenoids:** This group of compounds, which includes β-damascenone (cooked apple, floral), β-ionone (violet, raspberry), and TDN (1,1,6-trimethyl-1,2-dihydronaphthalene; kerosene/petrol note in aged Riesling), are breakdown products of carotenoids. They are notable for their extremely low sensory perception thresholds, meaning they can have a significant impact on the overall aroma profile even at minute concentrations (nanograms per liter).[45]
- **Methoxypyrazines:** 2-methoxy-3-isobutylpyrazine (IBMP) is the most well-known of this group, imparting potent herbaceous or "green" aromas reminiscent of bell pepper, asparagus, or pea pods. It is a key impact compound in varieties like Sauvignon Blanc, Cabernet Sauvignon, and Cabernet Franc. The concentration of methoxypyrazines is highest in unripe grapes and decreases significantly with increased sun exposure and throughout the ripening process.[42]

The Hidden Potential: Aroma Precursors

A significant portion of the grape's total aromatic potential exists in a non-volatile, odorless, "bound" state.[46] These

aroma precursors consist of a volatile aroma molecule (the aglycone) chemically linked to a non-volatile molecule, most commonly a sugar (forming a **glycoside**) or an amino acid (forming a cysteine or glutathione **conjugate**).[42]

During alcoholic fermentation and subsequent wine aging, these bonds can be broken through either enzymatic action (by enzymes released from yeast) or slow

acid-catalyzed hydrolysis.[46] This cleavage releases the volatile aroma compound, making it sensorially perceptible for the first time. This phenomenon explains why grape juice smells relatively simple, while the finished wine can exhibit a complex bouquet of aromas that were not present in the original fruit. The release of potent, volatile thiols—responsible for the characteristic passionfruit, grapefruit, and guava aromas of Sauvignon Blanc—from their odorless cysteine-conjugated precursors is a classic example of this process.[42]

The skin's composition is not static but is in constant interplay with its environment, particularly sunlight. This interaction is a critical modulator of final wine quality. Sunlight exposure is necessary to degrade undesirable green methoxypyrazines and to promote the synthesis of desirable anthocyanins and flavonols.[36] However, excessive sun can lead to sunburn, which damages the berry and can destroy delicate aroma compounds. This positions the skin as a dynamic chemical shield, and viticultural practices like canopy management and leaf thinning are essentially tools for the winemaker to manipulate the skin's environment to optimize its protective responses, which are inextricably linked to the development of color, flavor, and aroma.

The following tables provide a comparative overview of the key phenolic compound classes and a specific example of varietal differences in anthocyanin profiles.

Table 3: Key Phenolic Compound Classes in Grape Skin and Seeds

Phenolic Class	Primary Location	Core Chemical Structure	Key Role in Wine	Ripening Dynamic
Anthocyanins	Skin only	Flavonoid glycosides.[35]	Provide red/purple color; antioxidant.[17]	Synthesized and accumulate starting at *véraison*.[15]
Tannins (Proanthocyanidins)	Skin and Seeds	Polymers of flavan-3-ols (catechin, epicatechin, etc.).[40]	Provide astringency, bitterness, structure, and aging potential; antioxidant.[13]	Accumulate pre-*véraison*; undergo structural evolution (polymerization, softening) post-*véraison*.[12]

Flavonols	Skin primarily	Flavonoids (quercetin, myricetin, etc.).[17]	Act as co-pigments to stabilize and intensify red wine color; UV protection.[36]	Synthesis is induced by sunlight exposure throughout development.[17]

Table 4: Major Anthocyanidins and Flavonols in Selected Red Grape Varieties

Variety	Major Anthocyanin(s) (% of total)	Major Flavonol(s) (mg/kg of berries)	Key Sensory Implication
Gros noir	Malvidin-3-O-glucoside (72.7%).[17]	Quercetin-3-O-glucoside (39.5).[17]	Deep, stable, purple-red color due to high malvidin and high total anthocyanin content.
Cardinal	Peonidin-3-O-glucoside (59.3%).[17]	Quercetin-3-O-glucoside (18.3).[17]	Lighter, brick-red color due to dominance of peonidin and much lower total anthocyanin content.
Muscat noir	Malvidin-3-O-glucoside (41.1%), Peonidin-3-O-glucoside (34.6%).[17]	Quercetin-3-O-glucoside (36.6).[17]	A more complex color profile with a mix of red and purple hues.

The Seed: A Concentrated Source of Bioactive Compounds

The grape seed, though a small component of the berry by weight, is a chemically dense and highly significant part. While often considered a byproduct of the juice and wine industries, it is a concentrated reservoir of compounds that have a major impact on wine texture and are the basis for valuable commercial extracts.

Seed Tannins (Condensed Tannins/Proanthocyanidins)

Grape seeds are the single largest repository of phenolic compounds in the berry, containing an estimated 60% to 70% of the total extractable phenolics.[21] The vast majority of these are

condensed tannins, also known as **proanthocyanidins**.[52]

The structure of seed tannins differs significantly from that of skin tannins. Seed tannins are also polymers of flavan-3-ol units, but they are particularly rich in the monomers **catechin**, **epicatechin**, and the galloylated form, **epicatechin gallate**.[40] Critically, they generally have a lower mean degree of polymerization (mDP) than skin tannins, meaning they are composed of shorter polymer chains.[40]

This structural difference has a direct sensory consequence. The smaller size and higher degree of galloylation make seed tannins taste significantly more **bitter** and feel more **astringent** or "harder" on the palate compared to the "softer" tannins extracted from the skin.[11] The extraction of these compounds into wine is dependent on the presence of alcohol and is influenced by winemaking decisions such as fermentation temperature and the duration of maceration.[40] This presents a "risk/reward" element in red winemaking. A controlled extraction of some seed tannin can provide essential structure and backbone for long-aging wines like Cabernet Sauvignon. However, excessive extraction can easily overwhelm a wine with aggressive, unpleasant bitterness, particularly in more delicate varieties like Pinot Noir. Therefore, the management of seed tannin extraction is a key stylistic decision for the winemaker.

The proanthocyanidins are the primary bioactive compounds of interest in the production of **Grape Seed Extract (GSE)**, a popular dietary supplement. The total proanthocyanidin content in dry seeds can be substantial, around 35.3 mg/g.[52] These extracts contain a mixture of monomers, dimers, trimers, and larger oligomeric and polymeric proanthocyanidins.[52]

Grape Seed Oil

In addition to tannins, grape seeds are a source of valuable oil. Depending on the variety and growing conditions, seeds contain between 8% and 20% oil by dry weight.[20] This oil is typically extracted by pressing or with solvents as a byproduct of

the wine and juice industries.

The fatty acid composition of grape seed oil is its most notable feature. It is exceptionally rich in **unsaturated fatty acids**, which constitute 85% to 90% of the total oil content.[57] The profile is dominated by the omega-6 polyunsaturated fatty acid,

linoleic acid (C18:2), which typically makes up 66% to 78% of the total fatty acids.[50] The second most abundant is the omega-9 monounsaturated fatty acid,

oleic acid (C18:1), which ranges from 12% to 25%.[59] Saturated fatty acids, such as palmitic acid and stearic acid, are present in much smaller quantities, typically less than 10% each.[60]

Grape seed oil also contains other lipophilic (fat-soluble) compounds, including various forms of **Vitamin E** (tocopherols and tocotrienols) and **phytosterols**, which contribute to its stability and nutritional value.[50]

It is critical to recognize the duality of value presented by the seed, which is dictated by the extraction method. The seed contains two distinct classes of high-value compounds: hydrophilic (water/alcohol-soluble) polyphenols like proanthocyanidins, and lipophilic (oil-soluble) lipids. These two classes are largely mutually exclusive. When grape seed oil is produced, the vast majority of the valuable polyphenols remain behind in the solid "press cake" or defatted meal.[50] Conversely, when producing a polyphenol-rich Grape Seed Extract, the oil is not the target product. This creates two separate and divergent value chains from the same raw material and highlights a crucial distinction: the widely studied health benefits of "grape seed extract" are attributable to its polyphenol content, whereas the nutritional benefits of "grape seed oil" are related to its unique fatty acid and vitamin E profile.

Other Constituents

Beyond tannins and oil, grape seeds are composed of significant amounts of structural components. **Fiber** is the most abundant, making up approximately 40% of the seed's dry weight, followed by **protein** at around 10-11%.[6] Defatted grape seed meal is therefore not only a source of polyphenols but also a rich source of dietary fiber and plant-based protein.

The following table details the typical fatty acid profile of commercially available grape

seed oil.

Table 5: Typical Fatty Acid Composition of Grape Seed Oil

Fatty Acid	Chemical Formula	Type	Typical Percentage Range (%)
Linoleic Acid	C18:2	Omega-6 Polyunsaturated	66.0 – 78.2 [50]
Oleic Acid	C18:1	Omega-9 Monounsaturated	12.0 – 25.0 [60]
Palmitic Acid	C16:0	Saturated	6.0 – 9.0 [60]
Stearic Acid	C18:0	Saturated	3.0 – 6.0 [60]
Alpha-linolenic Acid	C18:3	Omega-3 Polyunsaturated	< 1.0 [60]

Integrated Significance and Industrial Valorization

The detailed examination of the grape berry's individual parts and their chemical constituents culminates in an understanding of their integrated significance. In oenology, the art of winemaking is fundamentally a process of selectively extracting and balancing these components. Beyond wine, the byproducts of this process have become the foundation for thriving industries centered on health and nutrition, representing a modern model of resource valorization.

An Oenological Synthesis: From Berry to Bottle

Winemaking can be conceptualized as a process of controlled deconstruction and re-integration of the grape berry's chemically distinct compartments. The final style and quality of any wine are a direct reflection of which compounds, from which parts of the berry, were extracted and stabilized in the final liquid medium.

- **White Wine Production:** The goal in most white winemaking is to produce a wine that is primarily an expression of the **pulp**. The grapes are typically crushed and pressed immediately, separating the juice (must) from the skins and seeds. The subsequent fermentation of this juice yields a wine whose character is defined by the balance of water, alcohol (from the pulp's sugars), and acidity (from the pulp's organic acids). Phenolic input from the skins and seeds is intentionally minimized to avoid bitterness and astringency. A notable exception is the production of "orange wines," where white grapes are fermented in contact with their skins for an extended period, intentionally extracting tannins, pigments, and other skin compounds to create a wine with a completely different textural and aromatic profile.[45]
- **Red Wine Production:** In stark contrast, red winemaking is an integrated process involving all three parts of the berry. The grapes are crushed, and the entire mixture of pulp, skins, and seeds is fermented together in a process called **maceration**.[40] During this time, the fermenting must, with its increasing concentration of alcohol and elevated temperature, acts as a solvent. The winemaker's task is to manage this extraction carefully to achieve a desired balance. Color (anthocyanins) and key aroma compounds are extracted from the skins. Textural components (tannins) are extracted from both the skins and the seeds.[40] The final red wine is therefore a complex chemical equilibrium between the pulp-derived base of alcohol and acid, and the skin- and seed-derived phenolics that provide color, aroma, structure, and aging potential.

Nutraceutical Applications: The Science of Grape Seed Extract (GSE)

The seeds removed during the winemaking process, once a waste product, are now the primary raw material for the production of **Grape Seed Extract (GSE)**, a major product in the global nutraceutical market.[64] The value of GSE lies in its high concentration of bioactive

proanthocyanidins.[6] A large body of scientific research has investigated the potential health benefits of these compounds, with the most robust evidence centered on cardiovascular health and antioxidant effects.

- **Cardiovascular Health:** Multiple clinical studies and meta-analyses support the role of GSE in promoting cardiovascular health. It has been shown to significantly reduce both systolic and diastolic blood pressure, particularly in individuals with

prehypertension or metabolic syndrome.[66] The proposed mechanism involves the enhancement of nitric oxide production, which leads to vasodilation (widening of blood vessels).[68] GSE has also been demonstrated to improve blood flow and reduce leg swelling (edema) associated with prolonged sitting.[67] Furthermore, some studies suggest it can help lower levels of LDL ("bad") cholesterol and, crucially, inhibit the oxidation of LDL, which is a key initiating step in the development of atherosclerosis.[64]

- **Antioxidant and Anti-inflammatory Effects:** The proanthocyanidins in GSE are potent antioxidants, with studies suggesting their free-radical scavenging activity is superior to that of well-known antioxidants like Vitamin C and Vitamin E.[70] Clinical research has shown that GSE supplementation can improve biomarkers of oxidative stress and reduce levels of C-reactive protein (CRP), a key systemic marker of inflammation.[64]
- **Other Potential Benefits:** Research into other areas is ongoing but promising. Preliminary evidence from animal and *in vivo* models suggests GSE may support bone health by promoting bone formation and increasing bone density.[67] It has also demonstrated antimicrobial activity against various foodborne pathogens.[70] Other areas of investigation include wound healing and the prevention of cognitive decline, though evidence in humans remains limited or inconclusive and requires further high-quality research.[71]

Beyond Wine and Supplements: Valorization of Grape Pomace

The complete solid residue left after pressing grapes for wine—a mixture of skins, seeds, and residual stems known as **grape pomace** or marc—is the single largest waste stream of the global wine industry.[5] The disposal of this organic material presents a significant environmental and economic challenge. However, this "waste" is a chemically rich raw material, and its valorization is a prime example of a circular bioeconomy in action. This approach transforms a costly waste problem into a sustainable source of high-value natural ingredients.

The applications for pomace are diverse. It is a rich source of **dietary fiber**, which can be extracted and used to fortify food products.[72] The skins from red grape pomace are a potent source of natural

anthocyanin pigments, which can be used as natural food colorants.[5] The high concentration of various phenolic compounds makes pomace extracts valuable as

natural

antioxidants to improve the shelf-life and stability of food products.[5] Furthermore, pomace contains residual proteins and oils, and its components are being explored for use in the cosmetic, pharmaceutical, and animal feed industries.[4] This comprehensive utilization closes the resource loop, creating new revenue streams from a byproduct and meeting growing consumer demand for natural, sustainable, and functional ingredients.

The following table summarizes the reported health benefits of Grape Seed Extract, contextualized with the level of scientific evidence available.

Table 6: Summary of Reported Health Benefits and Evidence for Grape Seed Extract (GSE)

Health Area	Specific Benefit	Proposed Mechanism	Level of Evidence	Key Supporting Sources
Cardiovascular	Blood Pressure Reduction	Enhances nitric oxide production, leading to vasodilation; antioxidant effects.[68]	Strong Clinical	[66]
	Improved Blood Flow / Reduced Edema	Blood-thinning effects; reduced platelet aggregation; improved endothelial function.[67]	Moderate Clinical	[67]
	Lowering LDL Cholesterol & Oxidation	Inhibition of LDL oxidation; may lower total and LDL cholesterol.[64]	Moderate Clinical	[66]
Systemic Health	Antioxidant Activity	Potent free radical scavenging by	Strong Clinical & In Vitro	[64]

		proanthocyanidins.[68]		
	Anti-inflammatory Effects	Reduction of inflammatory markers such as C-reactive protein (CRP).[68]	Moderate Clinical	[68]
Bone & Tissue	Improved Bone Strength	Promotes bone formation and mineral deposition; inhibits bone resorption.[67]	Preliminary (Animal Studies)	[67]
	Wound Healing Support	Anti-inflammatory, antimicrobial, and antioxidant properties support healing processes.[71]	Preliminary	[71]
Cognitive Health	Prevention of Cognitive Decline	Inhibition of oxidative stress in the brain; promotion of synaptic transmission.[68]	Preliminary / Inconclusive	[68]

Conclusion

The grape berry, *Vitis vinifera*, is a masterful example of biological design, where anatomical structure and chemical composition are inextricably linked to serve both reproductive function and, through human intervention, immense economic purpose. This report has systematically deconstructed the berry into its constituent parts—the pulp, skin, and seed—to reveal a highly compartmentalized biochemical factory. The pulp serves as the aqueous engine, a reservoir of water, sugars, and acids that provide the raw materials for fermentation. The skin acts as a dynamic sensory nexus, a protective shield that synthesizes and stores the pigments, aromas, and soft tannins

that define a wine's identity. The seed, in turn, is a concentrated source of structural tannins and valuable bioactive compounds, representing both a challenge for the winemaker and an opportunity for the nutraceutical industry.

The synthesis of these parts during winemaking is a process of controlled chemical integration, where the final product is a direct reflection of the compounds selectively drawn from each compartment. Beyond wine, the industrial valorization of grape byproducts, particularly pomace and seeds, exemplifies a successful circular bioeconomy, transforming a massive waste stream into a source of sustainable, natural ingredients for food, health, and cosmetic applications.

Looking forward, the intricate knowledge of the grape's composition opens new frontiers. Advanced breeding programs and genetic technologies hold the potential to develop new grape varieties tailored for specific chemical profiles—for instance, with enhanced levels of beneficial compounds like resveratrol, or with acid and sugar dynamics better adapted to a changing climate. This latter point represents the most significant challenge facing viticulture in the 21st century. Rising global temperatures are altering the delicate synchrony of ripening, often accelerating sugar accumulation while the more complex and lengthy process of phenolic maturation lags behind. Understanding and mitigating the impacts of climate change on the berry's intricate chemical balance will be paramount to preserving the quality and diversity of the world's grapes and the wines they produce for generations to come.

Sources

1. Virtual Grape Fruit Berries 1 - PLB Lab Websites, fecha de acceso: julio 4, 2025, https://labs.plb.ucdavis.edu/rost/virtual%20grape%20dreamweaver/Fruit%20Berries%201.htm
2. Anatomy of the fruit, its structure, and composition - Unacademy, fecha de acceso: julio 4, 2025, https://unacademy.com/content/neet-ug/study-material/biology/anatomy-of-fruit/
3. Fruit (plant structure) - Wikipedia, fecha de acceso: julio 4, 2025, https://en.wikipedia.org/wiki/Fruit_(plant_structure)
4. Chemical Composition and Health Benefits of Grape and Grape Products - ResearchGate, fecha de acceso: julio 4, 2025, https://www.researchgate.net/publication/391237663_Chemical_Composition_and_Health_Benefits_of_Grape_and_Grape_Products
5. Grape Pomace: A Review of Its Bioactive Phenolic Compounds, Health Benefits, and Applications - MDPI, fecha de acceso: julio 4, 2025, https://www.mdpi.com/1420-3049/30/2/362
6. Phytochemical Constituents, Health Benefits, and Industrial ..., fecha de acceso:

julio 4, 2025, https://pubmed.ncbi.nlm.nih.gov/28914789/
7. Grape cluster and berry structure – eVineyard blog, fecha de acceso: julio 4, 2025, https://www.evineyardapp.com/blog/2017/09/05/grape-cluster-and-berry-structure/
8. The grape berry and its characteristics - Tenimenti Civa, fecha de acceso: julio 4, 2025, https://tenimenticiva.com/article-blog/the-grape-berry-and-its-characteristics/?lang=en
9. Fruits | PPT - SlideShare, fecha de acceso: julio 4, 2025, https://www.slideshare.net/slideshow/fruits-43346364/43346364
10. grape berry development - OENO One, fecha de acceso: julio 4, 2025, https://oeno-one.eu/article/view/970/39127
11. Composition of Grapes | Wine, fecha de acceso: julio 4, 2025, https://www.extension.iastate.edu/wine/wp-content/uploads/2021/09/compositionofgrapes.pdf
12. Basic Grape Berry Structure – Grapes, fecha de acceso: julio 4, 2025, https://grapes.extension.org/basic-grape-berry-structure/
13. Grape Skin: What It Does and Why It Matters - Good Pair Days, fecha de acceso: julio 4, 2025, https://blog.goodpairdays.com/grape-skin-what-it-does-and-why-it-matters/
14. (PDF) Grapevine berry morphology and composition: A review - ResearchGate, fecha de acceso: julio 4, 2025, https://www.researchgate.net/publication/259649317_Grapevine_berry_morphology_and_composition_A_review
15. Grape Berries Anatomy and Transformation: From Early Development to Extra-Ripening, fecha de acceso: julio 4, 2025, https://www.viniramawine.com/post/the-fascinating-anatomy-of-vines-grape-berries
16. Malic Acid in Wine: Origin, Function and Metabolism during Vinification, fecha de acceso: julio 4, 2025, https://www.journals.ac.za/sajev/article/view/1613/737
17. Determination of major anthocyanin pigments and flavonols in red ..., fecha de acceso: julio 4, 2025, https://oeno-one.eu/article/view/56/0
18. Exploring Grape Essentials: Pulp, Skin, and Seeds in Winemaking - SOMM DIGI, fecha de acceso: julio 4, 2025, https://sommdigiblog.com/study/exploring-grape-essentials-pulp-skin-and-seeds-in-winemaking
19. Grape pulp is the main part of the grape, consisting of water, sugars - ResearchGate, fecha de acceso: julio 4, 2025, https://www.researchgate.net/figure/Grape-pulp-is-the-main-part-of-the-grape-consisting-of-water-sugars-acids-and-aroma_fig2_389060252
20. www.researchgate.net, fecha de acceso: julio 4, 2025, https://www.researchgate.net/figure/CHEMICAL-COMPOSITION-OF-GRAPE-SEEDS_tbl1_303892224#:~:text=Grape%20seeds%20(prior%20to%20oil,8%2C%2046%2C%2047%5D.

21. Analysis of Phenolic Content in Grape Seeds and Skins by Means of a Bio-Electronic Tongue - MDPI, fecha de acceso: julio 4, 2025, https://www.mdpi.com/1424-8220/20/15/4176
22. Did you know that grapes contain about 82% water and 99% of table grap... - TikTok, fecha de acceso: julio 4, 2025, https://www.tiktok.com/@whatsgoodberto/video/7283559948464688427
23. Water Amounts in Fruits and Vegetables - Handout Week 10.pub - Urban Worm Company, fecha de acceso: julio 4, 2025, https://urbanwormcompany.com/wp-content/uploads/2018/09/Water-Amounts-in-Fruits-and-Vegetables-Handout-Week-10.pdf
24. Sugars in wine - Wikipedia, fecha de acceso: julio 4, 2025, https://en.wikipedia.org/wiki/Sugars_in_wine
25. The Role of Glucose and Fructose in Wine and It's Frequent Measurement - Sentia, fecha de acceso: julio 4, 2025, https://sentiaanalysis.com/why-is-glucose-and-fructose-important-in-wine/
26. The Glucose-Fructose ratio of wild Tunisian grapes - Taylor & Francis Online, fecha de acceso: julio 4, 2025, https://www.tandfonline.com/doi/full/10.1080/23311932.2017.1374156
27. 222 Technical Review June 2016, fecha de acceso: julio 4, 2025, https://www.awri.com.au/files/attachment/technical_review_issue_223_wilkes/
28. Polysaccharide composition of grape cell walls deduced from the linkage... - ResearchGate, fecha de acceso: julio 4, 2025, https://www.researchgate.net/figure/Polysaccharide-composition-of-grape-cell-walls-deduced-from-the-linkage-composition_tbl2_225458278
29. Comparison of the sugar and organic acid components of seventeen table grape varieties produced in Ankara (Türkiye): a study over two consecutive seasons, fecha de acceso: julio 4, 2025, https://pmc.ncbi.nlm.nih.gov/articles/PMC10957544/
30. Comparison of the sugar and organic acid components of ... - Frontiers, fecha de acceso: julio 4, 2025, https://www.frontiersin.org/journals/plant-science/articles/10.3389/fpls.2024.1321210/full
31. Grape Tartaric Acid: Chemistry, Function, Metabolism, and Regulation, fecha de acceso: julio 4, 2025, https://www.mdpi.com/2311-7524/9/11/1173
32. Distribution and Effect of Grape Maturity on Organic Acid Content of Red Muscadine Grapes - American Chemical Society, fecha de acceso: julio 4, 2025, https://pubs.acs.org/doi/pdf/10.1021/jf00060a007
33. Organic acid profile of Turkish white grapes and grape juices | Request PDF - ResearchGate, fecha de acceso: julio 4, 2025, https://www.researchgate.net/publication/222407077_Organic_acid_profile_of_Turkish_white_grapes_and_grape_juices
34. Preparing for harvest: Grape chemistry and pre-fermentation adjustments, fecha de acceso: julio 4, 2025, https://extension.oregonstate.edu/crop-production/wine-grapes/preparing-harvest-grape-chemistry-pre-fermentation-adjustments

35. Biosynthesis of Anthocyanins and Their Regulation in Colored ..., fecha de acceso: julio 4, 2025, https://pmc.ncbi.nlm.nih.gov/articles/PMC6259108/
36. Midwest Grape and Wine Industry Institute - Pigments in Grapes ..., fecha de acceso: julio 4, 2025, https://www.extension.iastate.edu/wine/focusing-research-winemaking-pigments-grapes-anthocyanins/
37. Anthocyanin profile and antioxidant activity from 24 grape varieties cultivated in two Portuguese wine regions | OENO One, fecha de acceso: julio 4, 2025, https://oeno-one.eu/article/view/1661
38. Can anybody explain what is causing this? : r/wine - Reddit, fecha de acceso: julio 4, 2025, https://www.reddit.com/r/wine/comments/104is5d/can_anybody_explain_what_is_causing_this/
39. Grape Tannins Guide, fecha de acceso: julio 4, 2025, https://unpolishedgrape.com/grape-tannins-guide/
40. Midwest Grape and Wine Industry Institute - Tannins in Grapes, fecha de acceso: julio 4, 2025, https://www.extension.iastate.edu/wine/lets-focus-dr-watrelot-1/
41. The Science of Tannins in Wine | SevenFifty Daily, fecha de acceso: julio 4, 2025, https://daily.sevenfifty.com/the-science-of-tannins-in-wine/
42. Wine aromas and their precursors in grapes - Domaines François ..., fecha de acceso: julio 4, 2025, https://www.domainesfrancoislurton.com/en/wine-aromas-and-their-precursors-in-grapes/
43. The Actual and Potential Aroma of Winemaking Grapes - PMC, fecha de acceso: julio 4, 2025, https://pmc.ncbi.nlm.nih.gov/articles/PMC6995537/
44. Comprehensive aroma profiles and the underlying molecular mechanisms in six grape varieties with different flavors - Frontiers, fecha de acceso: julio 4, 2025, https://www.frontiersin.org/journals/plant-science/articles/10.3389/fpls.2025.1544593/full
45. Aroma Compounds from Grape Pomace: Investigation of Key ... - MDPI, fecha de acceso: julio 4, 2025, https://www.mdpi.com/2311-7524/11/3/302
46. (PDF) Aroma and Aroma Precursors in Grape Berry - ResearchGate, fecha de acceso: julio 4, 2025, https://www.researchgate.net/publication/281721752_Aroma_and_Aroma_Precursors_in_Grape_Berry
47. Grapevine Berry Structure & Development - YouTube, fecha de acceso: julio 4, 2025, https://www.youtube.com/watch?v=wReK_PR6eng
48. Meta-Analysis of the Core Aroma Components of Grape ... - Frontiers, fecha de acceso: julio 4, 2025, https://www.frontiersin.org/journals/plant-science/articles/10.3389/fpls.2016.01472/full
49. Delving Deep into Tannins: The Backbone of Wine Complexity, fecha de acceso: julio 4, 2025, https://www.willowcroftwine.com/blog/---Delving-Deep-into-Tannins--The-Backbone-of-Wine-Complexity

50. Evaluation of the Phytochemistry–Therapeutic Activity Relationship ..., fecha de acceso: julio 4, 2025, https://www.mdpi.com/2075-1729/13/1/178
51. Full article: Recovery of phenolic compounds from grape seeds: effect of extraction time and solid–liquid ratio - Taylor & Francis Online, fecha de acceso: julio 4, 2025, https://www.tandfonline.com/doi/full/10.1080/14786419.2010.524889
52. pmc.ncbi.nlm.nih.gov, fecha de acceso: julio 4, 2025, https://pmc.ncbi.nlm.nih.gov/articles/PMC6835351/#:~:text=%5B28%5D%20reported%20that%20the%20total,polymers%20were%20the%20most%20abundant.
53. Optimization of the Extraction of Proanthocyanidins from Grape ..., fecha de acceso: julio 4, 2025, https://www.mdpi.com/1420-3049/27/4/1363
54. Comparison of Proanthocyanidins in Commercial Antioxidants: Grape Seed and Pine Bark Extracts - ACS Publications, fecha de acceso: julio 4, 2025, https://pubs.acs.org/doi/pdf/10.1021/jf063150n
55. Grape Seeds Proanthocyanidins: An Overview of In Vivo Bioactivity in Animal Models - PMC, fecha de acceso: julio 4, 2025, https://pmc.ncbi.nlm.nih.gov/articles/PMC6835351/
56. Comparison of the chemical composition of grape seed oil extracted by different methods and conditions - Wiley Online Library, fecha de acceso: julio 4, 2025, https://onlinelibrary.wiley.com/doi/abs/10.1002/jctb.7314
57. Grape Seed Oil Compounds: Biological and Chemical Actions for Health - PMC, fecha de acceso: julio 4, 2025, https://pmc.ncbi.nlm.nih.gov/articles/PMC4988453/
58. Characterization of fatty acid, antioxidant, and polyphenol content of grape seed oil from different Vitis vinifera L. varieties | OCL - Oilseeds and fats, Crops and Lipids, fecha de acceso: julio 4, 2025, https://www.ocl-journal.org/articles/ocl/full_html/2021/01/ocl210003/ocl210003.html
59. Summary of fatty acid composition of grapeseeds. Ranges of... - ResearchGate, fecha de acceso: julio 4, 2025, https://www.researchgate.net/figure/Summary-of-fatty-acid-composition-of-grapeseeds-Ranges-of-fatty-acid-composition_tbl2_262451967
60. Grape seed oil - Wikipedia, fecha de acceso: julio 4, 2025, https://en.wikipedia.org/wiki/Grape_seed_oil
61. CAS 8024-22-4 Grape Seed Oil - Alfa Chemistry, fecha de acceso: julio 4, 2025, https://www.alfa-chemistry.com/product/grape-seed-oil-cas-8024-22-4-237314.html
62. CHEMICAL COMPOSITION OF GRAPE SEEDS (%) | Download Table - ResearchGate, fecha de acceso: julio 4, 2025, https://www.researchgate.net/figure/CHEMICAL-COMPOSITION-OF-GRAPE-SEEDS_tbl1_303892224
63. www.willowcroftwine.com, fecha de acceso: julio 4, 2025, https://www.willowcroftwine.com/blog/---Delving-Deep-into-Tannins--The-Backbone-of-Wine-Complexity#:~:text=Grape%20Skins%3A%20This%20is%20the,to%20gain%20color%20and%20flavor.
64. Grape seed extract - Wikipedia, fecha de acceso: julio 4, 2025, https://en.wikipedia.org/wiki/Grape_seed_extract

65. Key Leaders - Grape Seed Extraction Industry - Coherent Market Insights, fecha de acceso: julio 4, 2025, https://www.coherentmarketinsights.com/blog/insights/key-leaders-grape-seed-extraction-industry-340
66. Grape Seed Extract benefits, dosage, and side effects - Examine.com, fecha de acceso: julio 4, 2025, https://examine.com/supplements/grape-seed-extract/
67. 10 Benefits of Grape Seed Extract, Based on Science - Healthline, fecha de acceso: julio 4, 2025, https://www.healthline.com/nutrition/grape-seed-extract-benefits
68. 10 Benefits of Grape Seed Extract - Life Extension, fecha de acceso: julio 4, 2025, https://www.lifeextension.com/wellness/supplements/benefits-of-grape-seed-extract
69. Health Benefits of Grape Seed Extract - WebMD, fecha de acceso: julio 4, 2025, https://www.webmd.com/diet/health-benefits-grape-seed-extract
70. Grape seed extract: having a potential health benefits - PMC, fecha de acceso: julio 4, 2025, https://pmc.ncbi.nlm.nih.gov/articles/PMC7054588/
71. Grape seed extract: Benefits and side effects - MedicalNewsToday, fecha de acceso: julio 4, 2025, https://www.medicalnewstoday.com/articles/263332
72. (PDF) The Chemical Composition of Grape Fibre - ResearchGate, fecha de acceso: julio 4, 2025, https://www.researchgate.net/publication/276527040_The_Chemical_Composition_of_Grape_Fibre
73. Oxidation-Driven Assembly of Phenolic Compounds from Grape Seeds Waste into Nanoparticles as Potential Anti-Inflammatory and Wound Healing Therapies - ACS Publications, fecha de acceso: julio 4, 2025, https://pubs.acs.org/doi/10.1021/acsabm.4c01800