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Review

Retaining Resveratrol Content in Berries and Berry Products with Agricultural and Processing Techniques: Review

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Abstract: Resveratrol is a natural compound that can be found in red wine, grapes, and berries. It has attracted attention due to its potential health benefits. The aim of this review was to align ways of retaining resveratrol contents in berries and products made of berries, and to show which agricultural and processing techniques can maximize the content in the berries and their products and how this can be achieved. The scientific literature has revealed that resveratrol concentration in berries and berry-derived products varies significantly depending on the source and the processing techniques applied. Resveratrol content can range from 0.03–0.06 mg/kg in blueberries to 5–10 mg/kg in grape skins. Agricultural techniques such as controlled water stress (e.g., increasing resveratrol in grapes to 8.3–11.5 mg/kg), optimal sun exposure (e.g., enhancing blueberries to 1.5–2.1 mg/kg), balanced nutrient management, and selecting high-resveratrol cultivars (e.g., up to 15 mg/kg in certain grapes) can substantially increase resveratrol content. Processing methods like cold pressing, centrifugation, ultrafiltration, and freeze-drying are effective in preserving resveratrol levels, while traditional pasteurization tends to reduce its concentration. For instance, high-temperature short-time pasteurization can reduce resveratrol in juice from 1.5 mg/kg to 0.8 mg/kg, whereas cold pressing retains more resveratrol (1.5 mg/kg to 1.4 mg/kg). By optimizing these agricultural and processing techniques, manufacturers can enhance the resveratrol content in berry-derived products, meeting the growing consumer demand for health-enhancing natural products and supporting a healthier society. This approach aligns with the commitment to overcoming the technical challenges associated with resveratrol use, ensuring its potential is fully realized in both health-related and non-health-related applications.

Keywords: resveratrol; berries; berry products; natural products; influence of processes

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1. Introduction

Resveratrol (3,5,4′-trihydroxystilbene) is a phytoalexin belonging to the class of polyphenolic compounds called stilbene [1], isolated from grape berries, skin, and seeds for the first time in 1976 [2]. Resveratrol exists in trans- and cis- forms. Its molecular formula is $C_{14}H_{12}O_3$, with a weight of 228.24 g/mol, and the chemical structures of its trans- and cis-isomers are shown in Figure 1. These structures show that resveratrol contains three hydroxyl groups (-OH) bonded to the two benzene rings, which contribute to its antioxidant properties.

Resveratrol and its human metabolites are widely discussed in scientific research. It has low bioavailability and an extensive metabolism [3,4]. Recently, Springer, M, and Moko, S., discussed human metabolism and biotransformation of resveratrol, and reported molecular mechanisms of action [5]. Scientists have identified 4-hydroxydibenzyl as a novel gut microbiota-derived metabolite of resveratrol in humans [6–9], and the positive effects of resveratrol metabolites on human health have been discussed [10–13].

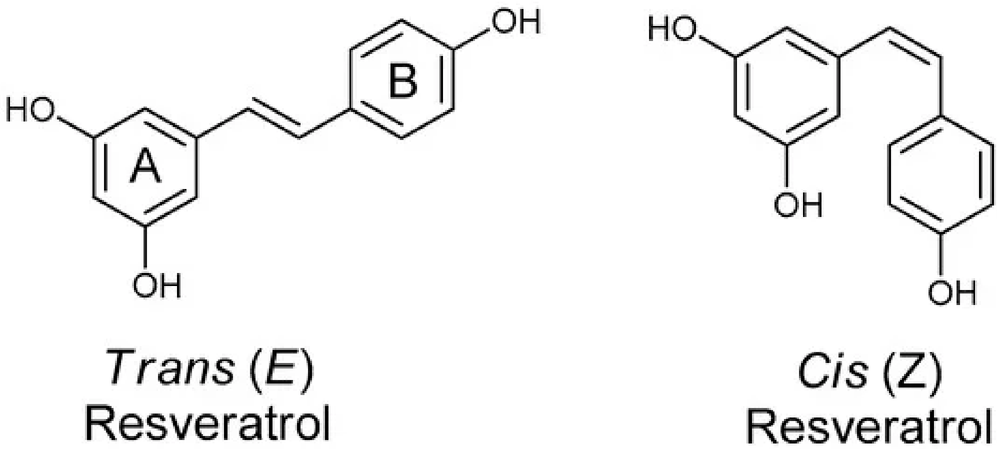

Figure 1. Chemical structures of trans-resveratrol and its cis-isomer.

Scientists revealed how specific resveratrol metabolites improve insulin resistance, highlighting their role in inhibiting cancer cell progression and enhancing the effectiveness of chemotherapy [14–16]. Resveratrol's antioxidant [17,18], anti-inflammatory [19,20], antibacterial [21], cardioprotective [22,23], anti-cancer [24,25], and potential anti-aging and neuroprotective [26] properties are widely discussed in recent scientific research. The field continues to evolve as researchers uncover new insights into resveratrol's metabolism, biological activity, and therapeutic potential for human health [27–29]. The typical dietary intake of resveratrol from these sources is relatively low, usually less than 1 mg per day, significantly lower than the doses commonly used in research studies. Consequently, the actual impact of dietary resveratrol remains unclear, largely due to the minimal amounts typically consumed through fresh berries [30–32].

Berries are an important natural source of resveratrol, particularly grapes [33,34] and strawberries. Additionally, red wine is produced by the fermentation of grapes and different types of wines contain different amounts of resveratrol [35,36]. Resveratrol synthesis in berries can be affected by various factors which increase resveratrol accumulation [37]. Some studies have delved into the impact of nitrogen supply on resveratrol concentrations in grape berries, alongside exploring methods for extracting resveratrol from blueberries.

This polyphenolic compound can also be found in various parts of the berry plant, notably in grapes, which have been extensively studied. Resveratrol is predominantly found in the skins of grape berries [38,39]. This is particularly significant as the skin is used extensively in the production of red wine, where resveratrol is extracted during the fermentation process [40–43]. Leaves also contain resveratrol, although the concentration can vary widely depending on the berry variety and the environmental factors affecting the plant [44,45]. Some studies have shown that resveratrol is present in the stems and vines of berry plants, suggesting that almost all parts of the plant can contribute to resveratrol content in various products derived from the vine [46].

The presence of resveratrol in these parts of the plant underscores its role in plant defense and its potential health benefits when consumed in products like wines, juice [47], or dried berries [48]. This distribution also highlights the importance of agricultural and processing techniques that can maximize the content of resveratrol from these parts for use in health supplements and functional foods. To maximize or maintain resveratrol content in fruits and wine, employing specific processing techniques is crucial. For fruits, gentle handling, cold storage, controlled atmosphere storage, minimal processing, and vacuum packaging are effective strategies. For wine, selecting high-resveratrol grape varieties, increasing skin contact time, optimizing fermentation temperatures, using antioxidants, controlled micro-oxygenation, proper aging conditions, stabilization techniques, and protective packaging can help preserve resveratrol levels. It can be concluded that avoiding high heat and minimizing light exposure are general best practices. These processing techniques collectively ensure that the beneficial properties of resveratrol are retained in both fruits and wine.

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart was used to systematically review and synthesize the relevant literature on resveratrol in berries and berry products. Records were identified through searches in multiple academic databases, including Google Scholar, Pubmed, MDPI, ScienceDirect, PubMed, Web of Science, Scopus, Food Science Source, European Patent Office, Agricola, and reputable websites. Keywords such as "Resveratrol", "Berries", "Berries' products", and "Impact of the processes" were used to locate relevant studies. The titles and abstracts of the identified records were screened to determine their relevance. The studies that met all the inclusion criteria were included in the final review and analysis. Inclusion criteria were as follows: (1) studies discussing resveratrol metabolism and biotransformation; (2) research on the health effects of resveratrol; (3) articles detailing agricultural techniques affecting resveratrol content; (4) studies on processing techniques influencing resveratrol in berries and products; (5) articles published in peer-reviewed journals; (6) studies providing quantitative data on resveratrol concentrations. Exclusion criteria were as follows: (1) studies not focused on resveratrol; (2) articles without substantial data on metabolism or health effects; (3) research not detailing agricultural or processing techniques; (4) duplicates and inaccessible full-text articles; (5) non-peer-reviewed articles, opinion pieces, and editorials; (6) studies published in languages other than English (unless translations were available). To complete this review, relevant articles were collected from the academic databases mentioned above. This flowchart in Figure 2 and the summary outline the process of identifying, screening, assessing, and including articles for the review, ensuring clarity and transparency in the research methodology. This methodical approach allowed the researchers to transparently report how they arrived at the final set of studies included in their review, providing a clear and concise summary of the literature selection process.

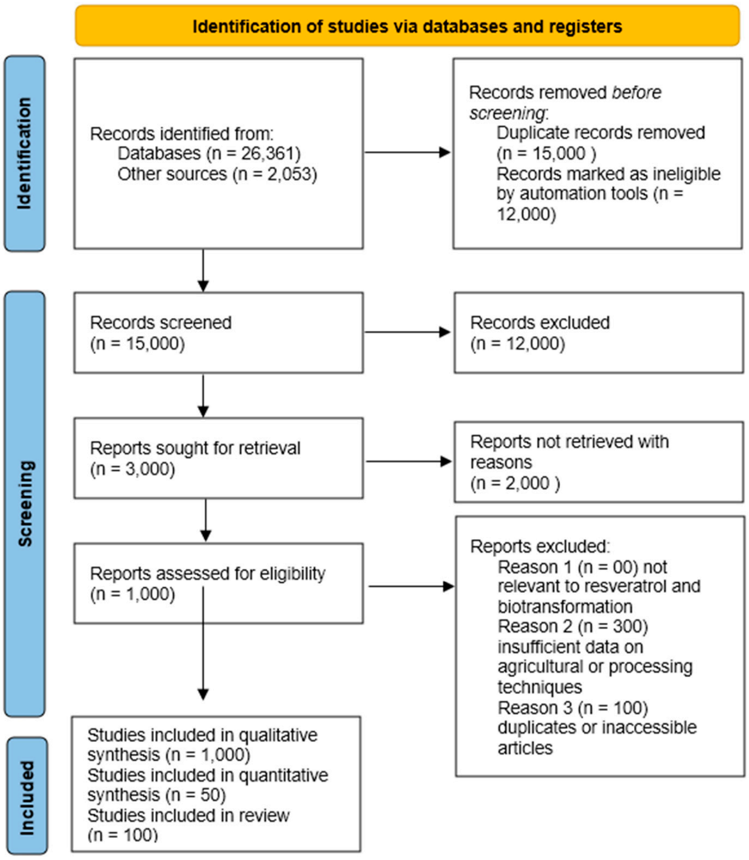

Figure 2. PRISMA flowchart on resveratrol in berries and berry products.

Relevant information was extracted from the selected articles and organized systematically. We analyzed the collected data, identified existing trends and gaps, compared and contrasted the findings of different studies, and critically evaluated the strengths and weaknesses of each piece of evidence. On this basis, we created the conceptual structure of our review article. We categorized our findings and they are presented in the tables.

Table data visualization software (PRISMA 2020) was used to create interactive and visually appealing dashboards and reports. It connects to various data sources and enables users to explore, analyze, and present data in a user-friendly manner. Therefore, it can be used in business intelligence, data analytics, and decision-making processes. Our aim was to follow this methodology to reveal how to retain resveratrol contents in berries and products made of berries, and to show how agricultural and processing techniques can maximize resveratrol content in the berries and berry products.

2. Agricultural Technologies

Resveratrol is predominantly associated with grapes, particularly red and purple grapes, as they are one of the richest sources of this compound, which is widely recognized due to its presence in red wine [49–51]. Notably, the Pinot noir grape variety contains the highest content of resveratrol, with concentrations reaching 5–10 mg/kg in the grape skins [52–55]. Blueberries contain resveratrol, though in smaller amounts than grapes. Both wild and cultivated blueberries have resveratrol, with variations depending on the specific type and growing conditions [56]. The concentration of resveratrol in blueberries, bilberries, strawberries, cranberries, mulberries, lingonberries, and raspberries can vary significantly depending on the specific type of berry and the environmental conditions in which they are cultivated [57–60]. Agricultural techniques play a critical role in influencing the production and retention of resveratrol in fresh berries, leaves, and stems [61,62]. From the agricultural methods found in the research, we identified the following, presented in Table 1.

Table 1. Agricultural technologies influencing resveratrol content in berries.

Agricultural Techniques	Description	Advantages	Disadvantages	Resveratrol Content (mg/kg)	Refs.
Water Stress	Controlled water stress, especially deficit irrigation, can significantly increase resveratrol concentration in berries. Limiting water at critical growth stages can induce a stress response in plants, leading to the enhanced synthesis of resveratrol as part of the plant's defense mechanism.	Enhances resveratrol production as a stress response; can also conserve water usage, making it environmentally sustainable.	Risk of under-irrigation leading to stress that could negatively impact overall plant health and yield if not carefully managed.	Grapes: 8.3–11.5 mg/kg	[63–66]
Sun Exposure	Ensuring optimal sun exposure can stimulate resveratrol production, as this is part of the plant's natural response to ultraviolet (UV) radiation. However, excessive sun exposure can be detrimental, so balance is key.	Proper sunlight exposure can naturally increase resveratrol production through UV-induced stress responses.	Requires careful management to avoid overexposure, which can lead to sunburn or heat stress, adversely affecting the plants.	Blueberries: 1.5–2.1 mg/kg	[67–71]
Nutrient Management	Adequate nutrition, especially phosphorus and nitrogen management, influences the general health of the plants and their ability to produce phytochemicals like resveratrol. However, excessive use of nitrogen can sometimes decrease phenolic compounds, so careful management is necessary.	Healthy soil supports overall plant growth and optimizes conditions for resveratrol production.	Balancing soil nutrients precisely to avoid over- or under-fertilization can be challenging.	Strawberries: 0.3–0.5 mg/kg	[72,73]

Table 1. *Cont.*

Agricultural Techniques	Description	Advantages	Disadvantages	Resveratrol Content (mg/kg)	Refs.
Organic Farming Practices	Some studies suggest that organic farming practices, which avoid synthetic pesticides and fertilizers, might enhance the level of resveratrol. This could be due to the increased reliance of the plant on its own defense mechanisms to combat pests and diseases.	Organic practices enrich soil biodiversity, enhancing plant resilience.	Organic fertilization often requires more labor and can be more costly than conventional methods.	Raspberries: 0.8–1.2 mg/kg	[74–76]
Cultivar Selection	Choosing berry varieties that are naturally high in resveratrol can be an effective way to ensure higher levels in the final produce. Genetic variability significantly affects resveratrol content.	Ensures a genetic advantage in producing more of the compound, potentially reducing the need for intensive agricultural inputs.	Limited availability of high-resveratrol cultivars and possible higher costs associated with obtaining these specialized varieties.	Grapes: Up to 15 mg/kg in certain cultivars	[77–79]
Biotic Stress	Introducing controlled amounts of biotic stress, such as exposure to certain pathogens or insects, can stimulate the production of resveratrol as a defensive phytoalexin. However, this needs to be carefully managed to avoid significant damage to crops.	Reduces reliance on chemical pesticides, promoting natural plant defense mechanisms	Can be labor-intensive and requires a deep understanding of pest and predator relationships. Initial setup and maintenance costs can be high.	Grapes: 9–12 mg/kg when exposed to Botrytis cinerea	[80–82]
Use of Fungicides	Certain fungicides might induce resveratrol synthesis as a stress response, although the reliance on chemical treatments can have other environmental or health implications.	The same as for biotic stress	The same as for biotic stress	Grapes: Variable, can induce significant increases	[83,84]
Harvest Time	The stage of maturity at harvest can impact the resveratrol content in berries. Generally, berries accumulate resveratrol as they mature, so timing the harvest to coincide with peak resveratrol levels can optimize resveratrol content in the harvested fruit.	Harvesting at peak maturity when resveratrol levels are highest ensures the maximum content is retained in the harvested berries.	Narrow harvest windows require precise timing and may conflict with market prices or labor availability.	Grapes: 10–15 mg/kg at peak maturity	[85–87]
Pruning and Canopy Management	Proper pruning and canopy management can affect the light and air penetration within the plant foliage, which influences overall plant health and its metabolic processes, including resveratrol production.	Proper handling and storage maintain resveratrol levels post-harvest, preserving the quality and extending the shelf life of berries.	Requires investment in storage facilities. Mishandling can quickly degrade quality, despite optimal pre-harvest conditions.	Grapes: Improved resveratrol with balanced canopy	[88–90]

The qualitative analysis of agricultural techniques reveals that various methods can significantly influence the resveratrol content in berries. The enhancement of resveratrol primarily occurs through the plant's natural stress responses, whether induced by controlled water stress [91], optimal sun exposure [92], or biotic stress [93] from pathogens or insects. Organic farming practices and cultivar selection also play crucial roles by leveraging natural plant defense mechanisms and genetic advantages, respectively. Organic farming practices, for instance, emphasize soil biodiversity and plant resilience, leading to potentially higher resveratrol levels. Cultivar selection ensures that genetically predisposed plants produce more resveratrol, reducing the need for intensive agricultural inputs. Biotic and abiotic stresses such as controlled pathogen exposure and optimal sun exposure further stimulate resveratrol synthesis as part of the plant's defense strategy. However, these methods come with challenges, such as the need for careful management to avoid adverse effects on plant health and yield. Techniques like water stress and biotic stress must be precisely controlled to achieve the beneficial stress response without causing harm to the plant. Similarly, managing sun exposure requires ensuring there is enough UV radiation to stimulate resveratrol production without causing heat stress or sunburn.

The stability and concentration of resveratrol in agricultural produce are primary indicators of the effectiveness of agricultural techniques. Studies show that water stress can increase resveratrol concentration in grapes from 8.3 to 11.5 mg/kg. Blueberries show resveratrol contents of 1.5 to 2.1 mg/kg under proper sun exposure. Proper nutrient balance is crucial, as excessive nitrogen can reduce phenolic compounds. Strawberries exhibit resveratrol levels of 0.3 to 0.5 mg/kg with balanced nutrients. Organic farming is labor-intensive and costlier but leads to resveratrol levels of 0.8 to 1.2 mg/kg in raspberries [94]. To optimize resveratrol content in berries, a combination of these agricultural techniques should be carefully implemented, considering the specific operational conditions required for each method. By carefully weighing the advantages and obstacles linked with each technique, farmers can effectively boost resveratrol levels in berries, thereby augmenting their nutritional and economic value [95].

3. Processing Technologies

The preservation of berries provides a multitude of benefits that extend beyond simply preserving their freshness. It significantly enhances their practical utility, safety, nutritional profile, and economic value. It can sometimes increase the concentration of certain nutrients and improve their bioavailability, making it easier for the body to absorb essential vitamins and antioxidants. Processed berry products offer convenience, providing quick and easy ways to incorporate berries into diverse dietary habits, from jams and juices to frozen berries that retain much of the nutritional value of fresh berries [96–101].

The discovery of resveratrol immediately attracted the attention of scientists and manufacturers. This is shown not only by the research, but also by the number of patented products, production methods, and technologies. The European patent office contains 26,361 patents related to resveratrol. The first patented product was unregistered in 1985, which included resveratrol and aimed to improve liver health. A patent search with the term “resveratrol and berries” led to 2053 results. Resveratrol is commonly included in the composition of various patented products, particularly in sectors like pharmaceuticals, nutraceuticals, cosmetics, and the food and beverage industries. There are patents focused on chemical derivatives of resveratrol that enhance its efficacy, stability, or bioavailability for therapeutic purposes, and formulations that use resveratrol as a key ingredient in health supplements aimed at providing anti-aging, anti-inflammatory, or antioxidant benefits, as it is a molecule with anti-inflammatory and anti-cancer activities [102–105]. Some of them focus on methods for infusing resveratrol into alcoholic beverages to provide health benefits alongside traditional consumption, and on standardizing the bioactivity and content of resveratrol in other products to ensure consistent health benefits [106–111].

These patents demonstrate the diverse applications of resveratrol across different industries, leveraging its health-promoting properties to enhance products ranging from dietary supplements to skincare items and beyond, and reflect the broad interest and ongoing innovation in utilizing resveratrol for various health-related applications, from enhanced synthesis methods to novel therapeutic derivatives. Each patent represents a step towards better understanding and leveraging resveratrol’s potential benefits.

At present, berries can be preserved using traditional or very innovative techniques. In this area of product production, as many production technologies have recently been invented, e.g., ultrasonic homogenization, the need for resveratrol in berry products remains underestimated [112]. Based on the largest supply of berry products on the market, we selected the most-used processing techniques and describe their effects in Table 2.

Table 2. Processing methods influencing resveratrol content in berry products.

Processing Technology and Product Form	Technical Characteristics	Resveratrol Content before Processing (mg/kg)	Resveratrol Content after Processing (mg/kg)	Influence on Resveratrol	Refs.
Pasteurization: High Temperature, Short Time *Juice*	Quickly heats the juice to a high temperature for a brief period to kill pathogens and deactivate enzymes.	1.5	0.8	Heat involved in pasteurization can reduce the levels of resveratrol due to thermal degradation.	[113,114]
Pasteurization: Low Temperature Long Time *Juice*	Uses lower temperatures but for longer durations, also aiming to minimize microbial growth and enzyme activity.	1.5	0.9	Heat involved in pasteurization can reduce the levels of resveratrol due to thermal degradation.	[115–119]
Cold Pressing *Juice*	Utilizes a hydraulic press to extract juice under cold conditions, preserving more nutrients and flavors.	1.5	1.4	Retains more resveratrol because it avoids heat	[120,121]
Centrifugation *Juice*	Separates juice from solids quickly using centrifugal force	1.5	1.4	Preserves resveratrol content because it inactivates microbes and enzymes at cold or room temperatures without the use of heat.	[122]
Ultrafiltration *Juice*	Uses semi-permeable membranes to clarify juice and remove particles without heating	1.5	1.4	Preserves resveratrol content well because it inactivates microbes and enzymes at cold or room temperatures without the use of heat.	[123]
Reverse Osmosis *Juice*	Concentrates juice by removing water through a semi-permeable membrane under pressure.	1.5	Data unavailable	The impact of the process has been little studied; no reliable information has been found	[124,125]
Flash Pasteurization *Juice*	Rapidly heats and cools juice to kill microbes while preserving quality.	1.5	Data unavailable	The impact of the process has been little studied; no reliable information has been found	[126]
Fermentation *Wine*	Uses carefully controlled temperatures and yeast strains to optimize the fermentation process. Converts malic acid into lactic acid, softening the wine's taste.	1.5	1.8	Fermentation can actually increase the availability of resveratrol in wine, as the process involves the conversion of compounds in grape skins into more bioavailable forms.	[127–134]
Oak Aging *Wine*	Wine is aged in oak barrels, which contributes to flavor complexity through slow oxygenation and infusion of wood compounds	1.8	Data unavailable	The impact of the process has been little studied; no reliable information has been found	[135]

Table 2. *Cont.*

Processing Technology and Product Form	Technical Characteristics	Resveratrol Content before Processing (mg/kg)	Resveratrol Content after Processing (mg/kg)	Influence on Resveratrol	Refs.
Oven Drying *Dried berries*	Utilizes conventional ovens or specialized drying ovens where temperature and airflow are controlled to ensure even drying.	1.5	Depends on temperature during processing	Depends on temperature during processing	[136,137]
Dehydrator Drying *Dried berries*	Uses electric dehydrators equipped with heating elements, fans, and air vents to provide a controlled environment for moisture removal.	1.5	1.2	This method is more consistent than oven-drying and is excellent for producing high-quality dried fruits.	[138]
Microwave Drying *Dried berries*	Employs microwave energy to rapidly heat and evaporate water from the fruit.	1.5	Data unavailable	The impact of the process has been little studied; no reliable information has been found	[139,140]
Freeze Drying (Lyophilization) *Dried berries*	Involves freezing the fruit and then reducing the surrounding pressure to allow the frozen water in the fruit to directly transition from ice to vapor.	1.5	1.4	Freeze-drying is excellent for preserving resveratrol as it removes water at low temperatures, thus avoiding the heat that causes degradation. This method best retains the biochemical structure of the berry, including resveratrol.	[141,142]
Spray Drying *Powdered extracts*	Converts liquid fruit extracts into a powder by spraying the liquid into a hot drying chamber where the moisture quickly evaporates, leaving behind fine particles of dry powder.	1.5	Data unavailable	The impact of the process has been little studied; no reliable information has been found	[143]

While the specific methods and technologies may vary significantly depending on the product type—juice, wine, or dried fruits—the overarching principles of food processing are fundamentally aligned. They focus on enhancing product appeal, ensuring safety, preserving nutritional and sensory qualities, and achieving economic benefits. As the food processing industry continues to evolve, these principles guide the development of innovative technologies and processing techniques that meet the growing demands of consumers for high-quality, safe, and flavorful food products. The processing methods and technologies discussed in the context of juices, wines, and dried products are deeply interconnected with the preservation and enhancement of resveratrol content in berry-derived products. Here is how these processes specifically relate to optimizing resveratrol levels.

Scientific research shows that resveratrol is sensitive to thermal degradation. Processes that use lower temperatures (e.g., cold pressing or freeze-drying) are more likely to preserve resveratrol content in berry products. In contrast, the high temperatures used in pasteurization or conventional drying may reduce resveratrol levels. Another aspect is time management: extended exposure to processing conditions can degrade resveratrol. Minimizing the process time, such as with flash pasteurization or quick drying methods, helps to preserve its content. It is worth noting that resveratrol oxidation can occur if berry products are exposed to air during processing. Techniques that limit oxygen exposure, such as vacuum-packing in dried products or inert gas-flushing during wine bottling, help maintain resveratrol integrity.

Ensuring the stability of berry products through pH control and microbial safety measures also indirectly benefits resveratrol preservation by preventing the conditions that might lead to its breakdown. Technological parameters as pH management are important in preserving berries. Maintaining an optimal pH during fermentation (wine making) not only influences the growth of yeast and bacteria but also affects the stability of resveratrol. A stable pH can help preserve resveratrol throughout the fermentation process. In drying processes, controlling humidity is crucial not only for moisture removal but also for preventing the hydrolytic degradation of sensitive compounds like resveratrol [144,145]. Utilizing advanced technologies such as high-pressure processing (HPP) or pulsed electric fields (PEF) can enhance the extraction and retention of resveratrol during juice processing by disrupting cell walls without using significant heat, thus releasing more resveratrol while maintaining its structure [146–150].

In summary, it can be concluded that the relationship between processing methods, common goals, and technological parameters is critical to how resveratrol is preserved and enhanced in berry products. By understanding and optimizing these aspects, producers can maximize the health benefits of resveratrol in their berry-derived products, making them more appealing to health-conscious consumers. These strategies highlight the importance of selecting appropriate processing methods to retain bioactive compounds, ultimately influencing the nutritional quality and market value of the final products.

4. Challenges and Future Development

The review of the relevant literature highlighted that retaining resveratrol in fresh berries involves navigating several challenges, such as environmental variability, the resource-intensive nature of optimal agricultural practices, genetic differences among berry varieties, and post-harvest degradation. Future strategies to overcome these issues include adopting precision agriculture to finetune growing conditions, developing genetically enhanced varieties with higher natural resveratrol production, improving post-harvest and storage technologies, and enhancing consumer awareness of resveratrol's benefits. Additionally, integrated supply chain management and supportive policies from governmental bodies can further aid in maintaining the high resveratrol content from the farm to the consumer. These efforts will require coordinated actions across multiple sectors, from agriculture to education and policy-making, to ensure berries retain their maximum health benefits.

Increasing the amount of resveratrol in processed berry products involves several techniques that focus on both maximizing the extraction from the berries and preserving the compound during processing. Our scientific literature analysis showed these to be the most effective strategies for the preservation of resveratrol in berry products. First of all, it should be mentioned that employing specific extraction methods can maximize the amount of resveratrol extracted from berries. Techniques like cold pressing, enzymatic extraction, or the use of solvents that effectively dissolve resveratrol can increase its concentration in the final product. Scientists note that it is useful to add antioxidants such as ascorbic acid (vitamin C) or other stabilizers during processing to protect resveratrol from oxidative degradation. These additives can help to maintain the stability and bioactivity of resveratrol throughout the shelf life of the product. Encapsulating resveratrol during processing can protect it from degradation due to environmental factors and enhance its absorption when consumed. Techniques like nanoencapsulation or liposomal encapsulation are effective in stabilizing resveratrol in food matrices [151–153].

To maximize resveratrol levels in products, innovative preservation techniques such as pulse electric fields or ultrasound treatments can be implemented. These methods disrupt the cell structures in berries, potentially increasing resveratrol release and preservation during processing [154]. Additionally, formulating products with resveratrol combined with other functional ingredients, like vitamin E, flavonoids from various plant sources, and omega-3 fatty acids, can stabilize resveratrol and enhance its bioavailability and efficacy, thanks to their synergistic antioxidant properties. It is essential to ensure that any method that is used complies with local and international food safety regulations [155–157]. Transparent labeling regarding the enhanced resveratrol content can inform consumers, empowering them to make health-conscious choices. Thus, consumers should be educated about resveratrol and its health benefits, as well as the available methods to preserve it in products [158,159].

Fermentation is the most significant and widely studied method at present. Fermenting berries can naturally increase the concentration of resveratrol. The fermentation process, especially when conducted under controlled conditions, can enhance the biosynthesis of resveratrol by activating certain pathways in the berries [160–162]. The authors would like to acknowledge that many scientists point out that more in-depth research is needed in this area.

Further investigation into the molecular mechanisms by which resveratrol exerts its effects can help to understand how it influences aging, cancer, cardiovascular health, and neurodegenerative diseases. Pinpointing specific pathways can lead to targeted therapeutic strategies and optimized dosages. The literature analysis shows that, despite the promising preclinical studies, there is a need for more comprehensive and large-scale clinical trials to confirm resveratrol's benefits in humans [163–166]. These studies should focus on specific health outcomes, optimal dosages, and long-term effects to validate its efficacy and safety. Developing new formulations that enhance the bioavailability and stability of resveratrol is crucial for maximizing its therapeutic potential. The research could focus on nanotechnology-based delivery systems, like liposomes or nanoparticles, to improve cellular uptake and targeted delivery. Also, investigating the synergistic effects of resveratrol with other compounds could lead to more effective therapies. Combining resveratrol with other nutraceuticals or pharmaceuticals might enhance its efficacy or mitigate the side effects. Scientists should stay updated on ongoing research in food science that could offer new insights or technologies for enhancing resveratrol content. Investing in research and development can lead to innovative solutions that keep your products at the forefront of health trends.

5. Conclusions

This paper reviewed and discussed the agricultural and processing techniques that influence the content of resveratrol in berries and berry products, and possible solutions for retention. The most significant conclusions are as follows:

Resveratrol is a versatile and valuable phytochemical with a wide range of sources and applications. Its benefits are leveraged in health and wellness industries, and ongoing research continues to uncover new potentials and refine existing technologies to harness its properties more effectively.

Various agricultural methods significantly influence the resveratrol content in berries. Resveratrol, which is primarily found in grapes and other berries, is affected by factors such as berry variety, soil quality, climate conditions, and agricultural techniques. Implementing effective agricultural techniques involves balancing the benefits and challenges. For instance, while water stress and biotic stress enhance resveratrol, they must be precisely managed to avoid harming the plant. Techniques like organic farming and cultivar selection offer sustainable benefits but come with higher costs and labor requirements.

Processing methods also significantly affect resveratrol content in berry products. Techniques that minimize heat and oxidative stress are more likely to preserve resveratrol. High-temperature processes like pasteurization reduce resveratrol levels. Techniques must be optimized to balance microbial safety, nutritional preservation, and resveratrol retention. Optimizing resveratrol content in berries involves a combination of precise agricultural practices, innovative processing techniques, and advanced research [167–169]. Balancing the benefits and challenges of these methods can enhance the nutritional and economic value of berry products, contributing to a healthier society.

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