UNIVERSITÀ DEGLI STUDI DI PADOVA
Dipartimento Territorio e Sistemi Agro-Forestali
Department of Land, Environment Agriculture and Forestry

Corso di Laurea Magistrale/Second Cycle Degree (MSc)
in Food and Health

# Sustainable applications of grape pomace for the production of functional foods

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## Abstract

Grape pomace (GP) represents a by-product of the wine industry rich in bioactive compounds, including dietary fibre and polyphenols. With millions of tons of grapes produced annually, a considerable portion is directed towards winemaking, generating substantial amounts of grape pomace as solid waste. This review paper investigates the application of grape pomace as a functional food ingredient, used to fortify a wide range of foods, such as bakery products, meat, fish, dairy products, snacks, and beverages. It discusses the health benefits associated with these fortified products, emphasizing the potential for improved nutrition and enhanced functional properties. Additionally, the review highlights the sustainability aspects of utilising GP, including waste reduction and efficient waste disposal practices. Several challenges and limitations are identified, such as the variability in composition, consumer acceptance, and processing complexities. Strategies to overcome these challenges are also presented, focusing on innovative approaches and technologies. The comprehensive analysis presented in this review underlines the potential of grape pomace as a valuable functional food ingredient, contributing to human health and sustainable waste management.

# Riassunto

La vinaccia rappresenta un sottoprodotto dell'industria vinicola ricco di composti bioattivi, tra cui fibre alimentari e polifenoli. Ogni anno vengono prodotti milioni di tonnellate di uva, perlopiù destinati alla vinificazione, generando notevoli quantità di vinaccia come rifiuto solido. Questo articolo analizza l'applicazione della vinaccia come ingrediente alimentare funzionale, utilizzato per arricchire un'ampia gamma di alimenti, come prodotti da forno, carne, pesce, latticini, snack e bevande. Il documento analizza i benefici per la salute associati a questi prodotti fortificati, sottolineando il potenziale di miglioramento della nutrizione e delle proprietà funzionali. Inoltre, si evidenziano gli aspetti di sostenibilità dell'utilizzo della vinaccia, tra cui la riduzione dei rifiuti e pratiche di smaltimento efficienti. Vengono identificate diverse sfide e limitazioni, come la variabilità della composizione, le complessità di lavorazione, e non da ultimo, l'accettazione da parte dei consumatori. Vengono inoltre presentate le strategie per superare queste sfide, concentrandosi su approcci e tecnologie innovative. L'analisi completa presentata in questo articolo sottolinea il potenziale della vinaccia come prezioso ingrediente alimentare funzionale, oltre che valido contributo alla salute umana e ad una gestione sostenibile dei rifiuti.

# I. Introduction

Grapes are one of the most produced crops worldwide (FAO, 2022). The global production of fresh grapes in 2021 was approximately 74.8 million tonnes (mt), with China being the largest producer (14.8 mt) followed by Italy (6.4 mt) and the USA (6.1 mt) (OIV, 2021). Out of the total, around 52% was used for pressing, primarily for wine production (34.1 mt) and the production of musts and juices (3.1 mt). Wine production in 2021 reached an estimated 262 million hectolitres, with Italy, France, and Spain being the top three producing countries (OIV, 2021).

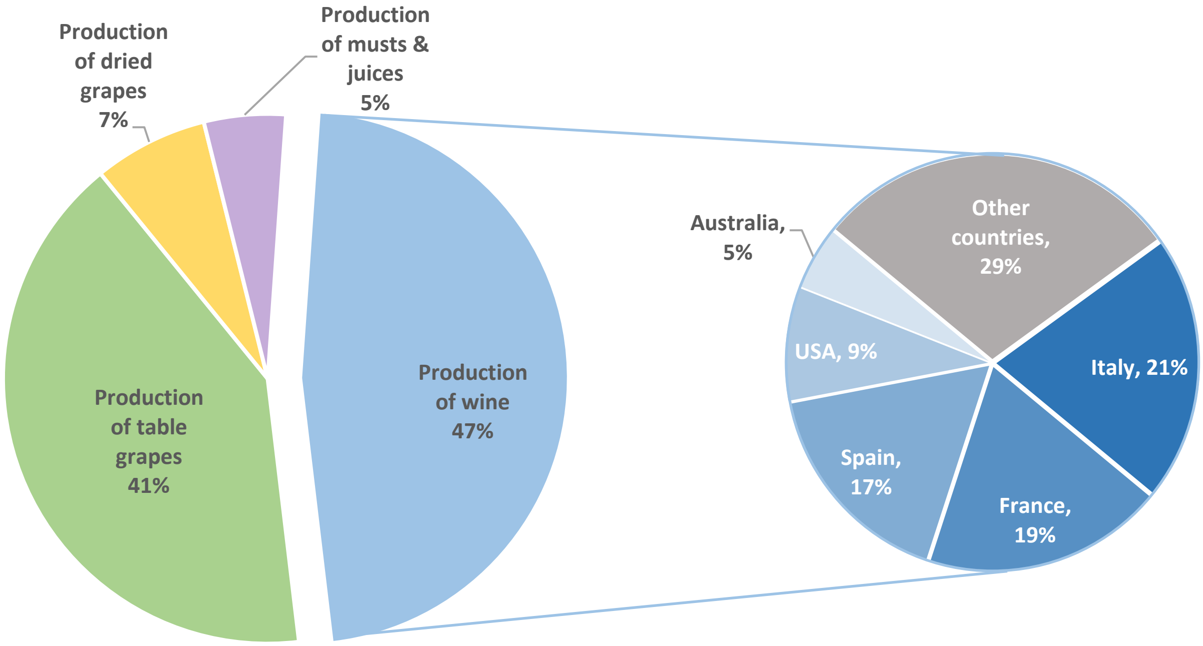

**Figure 1.** Breakdown of global grape production and the main wine producing countries

*Note*: Adapted from *Annual Assessment of the World Vine and Wine Sector in 2021* (OIV, 2021)

Grape pomace, or grape marc, is the by-product generated during the production of grape juice (must) by pressing whole grapes (Teixeira et al., 2014). GP consists of the skin, stem, residual pulp, and seeds of the grapes, with seed and skin representing a significant proportion of its dry weight (Beres et al., 2017).

Studies have shown that grape pomace typically accounts for 20-30% of the original grape weight (Beres et al., 2017; Dwyer et al., 2014), which amounts to approximately 7 – 11 million tonnes of grape pomace produced in 2021 alone. The amount of GP generated during winemaking depends on various factors, including grape variety, winemaking processes, and equipment used (Hogervorst et al., 2017). Due to the large volume generated during the limited winemaking period, it is important to implement sustainable methods for managing and utilising grape pomace efficiently and in an environmentally-friendly way (Chowdhary et al., 2021).

Conventionally, grape pomace has been managed through various practices that may not fully harness its potential and often result in environmental challenges. Distillation is one such practice where GP is used as a raw material for the production of alcoholic beverages, such as the Italian “grappa” (EC 1576/89). Despite the thermal degradation that occurs during the distillation process, spent grape pomace is still rich in dietary fibre and several bioactive compounds that could offer benefits for the food industry (Bordiga et al., 2015; Cisneros-Yupanqui et al., 2022). In a study by Cisneros-Yupanqui et al., (2022), the reduction in total phenolic content and antioxidant activity for red pomace was minimal, approximately 6% to 8%. Moreover, it was observed that white pomace demonstrated an increase in the concentrations of catechin, procyanidin B2, and epicatechin after distillation. This highlights the potential of distilled grape pomace for more beneficial applications, beyond its current usage as fertiliser or as a source for renewable energy (Bordiga et al., 2015).

Another common practice is using GP as a fertiliser in agricultural fields. However, direct land-spreading of pomace without proper processing can lead to environmental issues such as soil pollution, contamination of groundwater, and potential damage to vegetation (Amaya-Chantaca et al., 2022). Additionally, grape pomace has been incorporated into animal feed. Research studies have demonstrated that incorporating grape marc into the diet of dairy cows can lead to a reduction in methane emissions by around 15-20% (Moate et al., 2020, 2014). However, it is important to note that such diets may also result in a decrease in milk yields of approximately 10% (Moate et al., 2020). Furthermore, in another study involving sheep and dairy cows, the inclusion of grape pomace showed a negative impact on feed digestibility (Nistor et al., 2014). Based on these observations, it is advisable to use grape pomace in limited quantities when feeding ruminants (Nistor et al., 2014).

Different countries have established regulations governing the management and disposal of GP to mitigate environmental risks and promote responsible waste management practices. In the European Union (EU), the Commission Delegated Regulation (EU) 2019/934 establishes the rules for the disposal of grape pomace and wine lees. According to this regulation, winemakers must either transport the by-products to a distillery or vinegar production plant or withdraw them under the supervision of national authorities. In Italy, for example, grape marc is primarily sent to distilleries, but alternative methods for its utilisation are also authorised, including direct agronomic use, which implies the spreading on agricultural land (maximum 3000 kg per hectare); indirect agronomic use, consisting in the preparation of fertilisers; energetic use for biogas production; and cosmetic and pharmaceutical applications (Bello, 2020). In France, there have been specific regulations in place since 2014, that permit the composting and anaerobic digestion of grape marc and wine lees, as well as the spreading of grape marc (Lempereur and Penavayre, 2014).

Producers may be exempt from the requirement to withdraw their by-products if their annual production of wine does not exceed 50 hectolitres. This exemption raises concerns about the improper disposal of grape pomace and its potential accumulation in the fields. Small-scale wineries play a significant role in the wine industry, particularly in countries with a long-standing winemaking tradition, like Italy, France, and Spain. However, taking into account that these countries contribute to approximately 57% of global wine production (OIV, 2021), the potential damage caused by improper by-product management is substantial. .

In the United States, wine production is regulated by federal and state authorities, with waste management guidelines varying by state (Spigno et al., 2017). Options for pomace management include composting, anaerobic digestion, or sending it to authorised facilities for further processing (California Assembly Bill AB-1826).

As sustainability becomes increasingly important, exploring alternative and innovative approaches for grape pomace management is essential. GP is a valuable source of dietary fibre (Coelho et al., 2023; Lou et al., 2022) and is rich in phenolic compounds (Beres et al., 2017; Difonzo et al., 2023), known for their antioxidant properties and various health benefits (Herderich and Smith, 2005; Silva et al., 2023; Yang et al., 2022). Consumer's awareness about health has led to an increased demand for nutritious foods (Boff et al., 2022). Using wine by-products to enrich food not only addresses environmental concerns, but also promotes improved food quality and facilitates the creation of high-value products. This review aims to provide extensive and up-to-date information on the potential of grape pomace as a sustainable source of health-promoting compounds for the food industry. It covers various aspects related to grape pomace, including its nutritional value, bioactive compounds, and the impact of fortification on the quality of different food products.

# II. Nutritional value of grape pomace

The composition of grape pomace varies greatly depending on several factors, including the grape variety, level of maturity, environmental conditions (Iuga and Mironeasa, 2020), but also on the viticultural practices and methods of processing (Nakov et al., 2020). This explains why different sources mention different concentrations of nutrients. Table 1 presents the composition of grape pomace characterised by several authors.

## 2.1 Moisture content

Grape pomace resulted immediately after the pressing of grapes exhibits a high moisture content ranging from 50% to 72%, depending on its origin and the technologies applied (Teixeira et al., 2014). This might constitute a problem, as it can support microbial and enzymatic degradation, which could potentially affect the suitability of its use in food applications. As a result, the grape pomace, either fresh or distilled, has to be dried in order to reduce its water content and make it microbiologically stable. (Antonić et al., 2020; Bianchi et al., 2022)

After drying the GP, its moisture content varied between 0.92% and 14.96% in the analysed papers (Table 1). The variability could be explained by the drying method, time and temperature used, as well as the origin and variety of samples. This low moisture content naturally preserves the pomace by inhibiting microbial degradation. In a process described by Nakov et al., (2020), the pomace was dried in a forced air circulation oven at 60 °C for 48 hours. The dried residue was ground using a domestic blender and a powder with low moisture (4.04 ± 0.06 g/100g) was obtained. In another experiment, Cilli et al., (2020) dried the grape pomace in an oven with forced air circulation at 40°C for 72 hr. After milling, the resulting moisture content of the grape pomace flour was 14.96%, which indicates that a lower temperature of drying determines a higher moisture content.

**Table 1.** Proximate composition of grape pomace (skins and/or seeds), expressed in g/100 g dry weight (DW)

| Grape pomace fraction, variety | Moisture | Proteins | Lipids | Carbohydrates | Dietary fibre | Ash | Reference |
|---|---|---|---|---|---|---|---|
| **White grape pomace** | 0.97 ± 0.10 | 8.34 ± 0.02 | 14.14 ± 0.17 | - | 57.82 ± 0.76 | 1.23 ± 0.01 | (Coelho et al., 2023) |
| **Red grape pomace** | 0.92 ± 0.09 | 8.51 ± 0.02 | 12.58 ± 0.23 | - | 55.98 ± 0.96 | 2.50 ± 0.01 | (Coelho et al., 2023) |
| **Red grape pomace Cabernet Sauvignon** | 5.86 ± 0.55 | 13.61 ± 0.97 | 17.42 ± 1.15 | - | 65.10 ± 2.1 | 5.12 ± 0.87 | (Lou et al., 2022) |
| **Red grape skins Cabernet** | - | 13.86 ± 0.10 | 4.38 ± 0.15 | - | 57.02 ± 0.17 | 9.92 ± 0.07 | (Rainero et al., 2022) |
| **Red grape skins Primitivo** | - | 13.00 | 8.00 | - | 45.00 | 9.00 | (Troilo et al., 2022) |
| **White grape pomace Chardonnay** | 9.53 ± 0.31 | 9.17 ± 0.44 | 10.30 ± 0.93 | 44.18 ± 1.78 | 22.62 ± 1.34 | 4.16 ± 0.04 | (Fontana et al., 2022) |
| **White grape pomace Gewürztraminer** | 12.39 ± 0.20 | 9.31 ± 0.12 | 8.71 ± 1.29 | 51.93 ± 1.33 | 14.52 ± 0.47 | 4.16 ± 0.04 | (Fontana et al., 2022) |
| **White grape pomace Sauvignon Blanc** | 8.51 ± 0.05 | 10.00 ± 0.42 | 6.56 ± 0.24 | 55.92 ± 0.70 | 15.61 ± 0.43 | 3.38 ± 0.01 | (Fontana et al., 2022) |
| **Distilled red grape skins Cabernet** | 11.0 | 12.8 ± 0.3 | - | - | 55.6 ± 1.7 | 12.9 ± 0.2 | (Bianchi et al., 2022) |
| **Red grape pomace Isabel** | 13.78 ± 0.06 | 6.58 ± 0.10 | 2.75 ± 0.02 | 71.41 ± 0.27 | 31.64 ± 0.21 | 2.75 ± 0.16 | (Oliveira et al., 2022) |
| **Red grape pomace Isabel** | 14.96 ± 1.56 | 6.58 ± 0.22 | 2.75 ± 0.04 | 40.53 ± 1.34 | 31.79 ± 0.01 | 2.75 ± 0.33 | (Cilli et al., 2020) |
| **Red grape skins Corvina** | 11.0 ± 0.2 | 11.19 ± 0.97 | - | - | 52.3 ± 2.1 | 4.17 ± 0.87 | (Tolve et al., 2020) |
| **Red grape pomace Muscat Hamburg** | 4.04 ± 0.06 | 15.48 ± 0.98 | 14.95 ± 0.06 | - | 54.4 ± 1.46 | 6.51 ± 0.01 | (Nakov et al., 2020) |

## 2.2 Proteins

Grape pomace, including both the skins and seeds, is known to have a substantial protein content, which can range from 6% to 15% of the dry matter (Table 1). The protein content may vary depending on the grape variety and harvesting conditions. Both the skins and seeds of the wine pomace have a similar proportion of protein, but the skins tend to be slightly richer than the separated seeds (Coelho et al., 2023).

Several studies have explored the protein content of grape pomace in various forms (Table 1). The protein content of grape pomace samples analysed by Oliveira et al., (2022) was reported to be 6.58 ± 0.10 g/100g. The same content was reported by Cilli et al., (2020), as they used the same grape variety, Isabel. Coelho et al., (2023) found that the protein content ranged from 8.31 to 8.52 g/100 g, depending on the variety. Comparisons with other grape varieties reveal that the protein content of Sauvignon Blanc grape pomace (10.00% dry matter) can be higher than that of Gewürztraminer (9.31% dry matter), and Chardonnay (9.17% dry matter) (Fontana et al., 2022).

The amino acid profile of wine pomace, including both skins and seeds, resembles that of cereals, being rich in glutamic acid and aspartic acid but deficient in tryptophan and sulphur-containing amino acids (García-Lomillo and González-SanJosé, 2017). Grape seeds contain arginine, glutamic acid, aspartic acid, and glycine, whereas grape peels are richer in aspartic acid, lysine, glutamic acid, and leucine. It is important to note, however, that grape protein is classified as resistant due to protein-tannin complex structures reducing the protein digestibility (Oliveira et al., 2022).

## 2.3 Lipids

Wine pomace contains a significant amount of lipids, with the primary contribution coming from the seeds. Studies have shown that grape seeds in wine pomace typically have a lipid content ranging from approximately 3% to 15% (Table 1). The lipid fraction in grape seeds is characterized by a rich profile of polyunsaturated and monounsaturated fatty acids, with low levels of saturated fatty acids. Linoleic acid, constituting approximately 61 - 65% of the fatty acid profile, is the most abundant fatty acid in grape seeds. Oleic acid, accounting for around 16 - 18%, is another prominent fatty acid found in grape seed oil (Iqbal et al., 2021). Additionally, palmitic and stearic acids contribute to the saturated fatty acid profile, making up approximately 8 - 11% and 4 – 5%, respectively of the oil composition (Carmona-Jiménez et al., 2022). The high content of unsaturated fatty acids in grape seed oil makes it nutritionally valuable. These fatty acids have been associated with various health benefits, including reducing inflammation (Raphael and Sordillo, 2013), improving cardiovascular health, and promoting healthy skin (Gitea et al., 2023).

It is worth noting that the composition of lipids in GP can vary depending on factors such as grape variety, growing conditions, and winemaking processes. Therefore, the specific profile of lipids and phenolic compounds in grape by-products may differ between different sources and batches (Mohamed Ahmed et al., 2020).

## 2.4 Carbohydrates

Carbohydrates play a crucial role in human health, serving as the body's preferred source of energy (Baldán et al., 2021). Grape pomace flour was found to have total carbohydrate contents ranging between 40 and 71 g/100g (Table 1). It is worth noting that certain sources consider dietary fibre as part of the carbohydrate composition (Oliveira et al., 2022), while others do not. This discrepancy accounts for the observed variability in the reported carbohydrate content.

Grape pomace is known to be rich in sugars, with the highest quantities found in the skins (Iuga and Mironeasa, 2020). Sousa et al., (2014) analysed pomace from Brazilian Benitaka grapes, which were found to contain 29.20 g/100g of sugars, with fructose being the most abundant (8.91 g/100g) followed by glucose (7.95 g/100g), while no significant values for sucrose were observed. Canalejo et al., (2022) compared red and white pomace for the carbohydrate composition of their extracts. In both cases, the most prevalent monosaccharide was glucose (126.7 mg/g in red pomace; 224.3 mg/g in white pomace), followed by galactose (70.1 mg/g in red pomace; 120.3 mg/g in white pomace) and galacturonic acid (64.3 mg/g in red pomace; 74.7 mg/g in white pomace).

## 2.5 Dietary fibre

In the European Union, regulation (EU) 1169/2011 defines fibre as “carbohydrate polymers with three or more monomeric units, which are neither digested nor absorbed in the human small intestine”. Fibre can be naturally occurring in food or synthetic, but it should still demonstrate a beneficial physiological effect supported by scientific evidence. Similarly, the United States Food and Drug Administration (FDA) defines fibre as “non-digestible soluble and insoluble carbohydrates, with three or more monomeric units, as well as lignin, that are intrinsic and intact in plants”. It also includes “isolated or synthetic non-digestible carbohydrates with three or more monomeric units that have been determined by the FDA to have beneficial physiological effects for human health” (FDA, 2021). Dietary fibres can be categorized into two main types: insoluble fibres, such as cellulose, hemicellulose, and lignin, and soluble fibres, including pectin, inulin, gums, and mucilage (Spinei and Oroian, 2021). Dietary fibre is an important component found in dried wine pomace, with concentrations ranging from 14 to 65% (Table 1). Grape pomace, including both skin and seeds, is considered a valuable source of dietary fibre due to its high content of non-amidic polysaccharides, such as cellulose, xyloglucan, arabinan, pectin, and lignin (Beres et al., 2019). Among the different types of dietary fibre in grape pomace, soluble fibres, such as pectin, and insoluble fibres, including cellulose, hemicelluloses, and lignin, are prominent (Iuga and Mironeasa, 2020). Different varieties of grapes can exhibit variations in their fibre content. For example, the Cabernet variety has significantly higher crude fibre content compared to other varieties (Table 1). The high fibre content of grape pomace makes it a potential source of dietary fibre supplementation. The European Commission has gathered dietary recommendations for dietary fibre intake from food- and health- related organisations, which recommend a daily intake of approximately 25-30 g of dietary fibre (European Commission, 2021). A 10 g portion of grape pomace flour can provide more than 5 g of total dietary fibre, contributing to 20% of the recommended daily intake (Beres et al., 2019)

The consumption of an adequate amount of dietary fibre is linked to numerous health benefits. Firstly, it aids in maintaining regular bowel movements and preventing constipation. Insoluble fibres, such as cellulose and hemicelluloses, add bulk to the stool, promoting its movement through the digestive system and preventing constipation (Haque et al., 2023). The lignin content in grape pomace has been associated with beneficial physiological effects, including laxation, attenuation of blood cholesterol, and attenuation of blood glucose levels (Baldán et al., 2021).

Secondly, dietary fibre has been associated with weight management. High-fibre foods tend to be more filling and can help control appetite, leading to reduced calorie intake and potential weight loss (Haque et al., 2023). By incorporating grape pomace fibre into the diet, individuals can increase their fibre intake without significantly increasing their calorie consumption.

Moreover, the presence of dietary fibre in grape pomace enhances the release and fermentation of short-chain fatty acids (SCFAs) in the colon. SCFAs, particularly butyrate, are essential for maintaining the health of the colonic cells and promoting a favourable gut microbiota composition (Beres et al., 2019). A healthy gut microbiota is associated with improved digestion, enhanced immune function, and reduced risk of inflammatory bowel diseases and certain types of cancer (Quaglio et al., 2022)

## 2.6 Minerals

The mineral content of grape pomace can vary depending on the grape variety, cultivation conditions, climate, and ripening stage (García-Lomillo and González-SanJosé, 2017). Different parts of the grape, such as the skin, seeds, and stems, also exhibit variations in mineral composition. Grape skins tend to have higher levels of potassium, while seeds serve as a reservoir for calcium, phosphorus, sulphur, and magnesium. Other minerals present include manganese, iron, zinc, and copper (Barriga-Sánchez et al., 2022).

The ash content reflects the mineral concentration of grape pomace. Red GP generally contains higher ash content compared to white GP (Table 1), which can be attributed to the winemaking process. During red wine production, the grape skins and must are fermented together, allowing for greater extraction of minerals from the skins. On the other hand, white grape marc is obtained before fermentation, so there is less opportunity for mineral extraction from the grape skins (Coelho et al., 2023). Grape pomace, particularly the dry extract obtained from it, can serve as a natural dietary supplement due to its rich mineral content. The minerals present in grape pomace offer nutritional benefits and contribute to the antioxidant potential of the extract. For instance, iron and zinc, which are essential minerals found in grape pomace, have been shown to have a significant impact on the antioxidant potential (Antonić et al., 2020). Additionally, the higher levels of potassium compared to sodium can help promote a mineral balance that favours hypertension control (Sousa et al., 2014).

## 2.7 Vitamins

Grape pomace contains tocopherols and tocotrienols, which are Group E vitamins present in grape seeds. They exhibit various biological effects, including antioxidant, anti-inflammatory, and antithrombotic properties (Amaya-Chantaca et al., 2022). One interesting finding is that red grape seeds contain a higher concentration of tocopherol compared to white seeds (Iuga and Mironeasa, 2020). The content of vitamin E in grape seed oil can range from 1 to 53 mg/100 g of oil and is influenced by factors such as grape variety, environmental conditions, and cultivation practices (Spinei and Oroian, 2021). Additionally, Tikhonova et al., (2021) identified several water-soluble vitamins in grape pomace, including thiamine (B1), which was found to be the most abundant, followed by ascorbic acid, riboflavin (B2), nicotinic acid (B3), pantothenic acid (B5), and biotin (B7). The concentrations of these vitamins varied depending on the grape variety from which the pomace was obtained (Tikhonova et al., 2021).

## III. Bioactive compounds in grape pomace

Grape pomace has gained considerable attention in recent years due to its potential as a source of bioactive compounds with added health benefits to the consumers. Research indicates that polyphenols possess antioxidant, antimicrobial, anti-inflammatory, anticancer, and antithrombotic properties (Kalli et al., 2018). Fontana et al., (2022) integrated grape pomace flour into cookies and evaluated the content of phenolic compounds and its antioxidant capacity. The results showed a proportional rising of antioxidant activity in the samples of grape varieties containing a higher content of polyphenols. dos Santos Silva et al., (2022) and Tolve et al., (2020) also reported a high correlation between the amount of phenolics and the antioxidant potential of grape pomace flours and extracts.

Phenolic compounds are abundant in grape pomace. Beres et al., (2019) have estimated that after the production of wine, 70% of phenolics remain in the pomace. This phenomenon can be attributed to the partial extraction during the winemaking process (Antonić et al., 2020). Total phenolic content (TPC) varies depending on the grape variety, but also on the fraction of grape pomace used (skins, seeds and/or stalks) (Amaya-Chantaca et al., 2022). The highest TPC is found in grape seeds (60-70%), followed by skins (30-35%) and pulp (<10%) (Sirohi et al., 2020; Zhou et al., 2022). Other factors influencing the polyphenol content include agro-climatic conditions, grape berry ripening process, as well as processing and storage conditions, extraction and analytical methods (Barriga-Sánchez et al., 2022; Difonzo et al., 2023; García-Lomillo and González-SanJosé, 2017; Iuga and Mironeasa, 2020; Kalli et al., 2018). Particle size of the grape pomace flours (GPF) is also significant in this matter. Iuga and Mironeasa, (2020) showed that a higher total phenolic content is achieved with smaller particle size of GPF. The increase of extraction yield can be explained by a better surface contact (Iuga and Mironeasa, 2020).

Beres et al., (2017) classified the phenolic compounds from grape pomace into simple phenols and polyphenols. Simple phenols, also called phenolic acids in other sources, include hydroxybenzoic and hydroxycinnamic acids. Polyphenols are comprised of: (i) Flavonoids including flavonols, flavanols and anthocyanins; (ii) stilbenes including resveratrol; and (iii) tannins including proanthocyanidins, gallotannins and ellagitannins. The most abundant phenolics in GP are anthocyanins (in red grape skins), flavonols, hydroxybenzoic acids, hydroxycinnamic acids, and stilbenes (Fontana et al., 2013).

## 3.1 Phenolic acids

Phenolic acids are a diverse class of phenols found in grape pomace, characterized by the presence of a functional carboxylic acid group. They can be divided into two subgroups: hydroxybenzoic acids and hydroxycinnamic acids (Sirohi et al., 2020). Hydroxybenzoic acids, including gallic acid, p-hydroxybenzoic acid, protocatechuic acid, vanillic acid, and syringic acid, share a common C6–C1 structure (Figure 2). On the other hand, hydroxycinnamic acids, such as caffeic, ferulic, p-coumaric, chlorogenic and sinapic acids, have an aromatic structure with a three-carbon side chain (C6–C3) (Figure 2) (Balasundram et al., 2006; Beres et al., 2017). Hydroxycinnamic acids are often found in their free form in foods, except in frozen, sterilised, or fermented products. However, they can also exist in a bound form, usually as glycosylate derivatives or esters of quinic, tartaric, and shikimic acids (Sirohi et al., 2020).

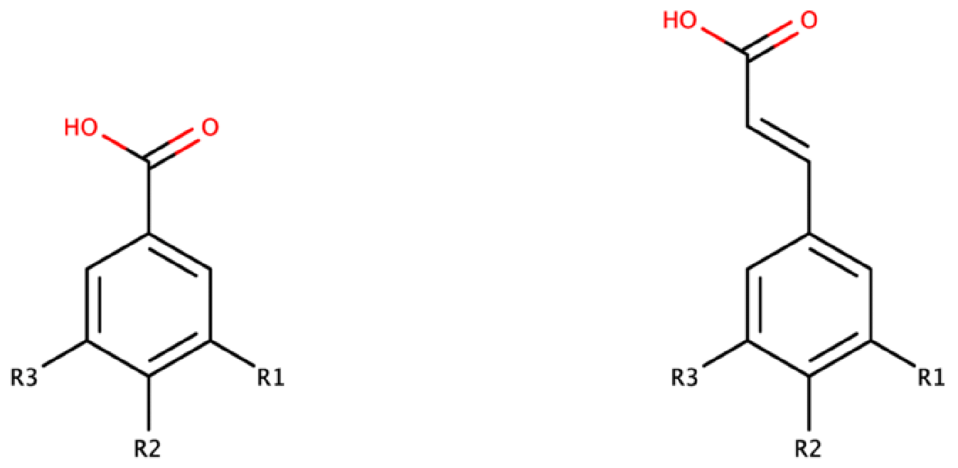

**Figure 2.** General structure of hydroxybenzoic acids (left) and hydroxycinnamic acids (right)

*Note*: Adapted from *Factors affecting intake, metabolism and health benefits of phenolic acids: do we understand individual variability?* (Bento da Silva et al., 2020)

## 3.2 Flavonoids

Flavonoids constitute the largest group of plant phenolics, comprising over half of the naturally occurring phenolic compounds (Balasundram et al., 2006). Structurally, flavonoids consist of two aromatic rings, A and B, joined by a heterocyclic pyrane ring (ring C) (Figure 3). The acetate/malonate pathway contributes to the formation of ring A, while ring B is derived from phenylalanine through the shikimate pathway (Silva et al., 2023). The major classes of flavonoids include flavones, flavonols, flavanones, flavanols, isoflavones, flavanonols, and anthocyanidins (Sirohi et al., 2020). Flavanols are responsible for many sensorial characteristics of wine. Grape seeds have the highest concentration of these compounds, containing catechins and procyanidins, while grape skins contain catechins and gallocatechins (Beres et al., 2017).

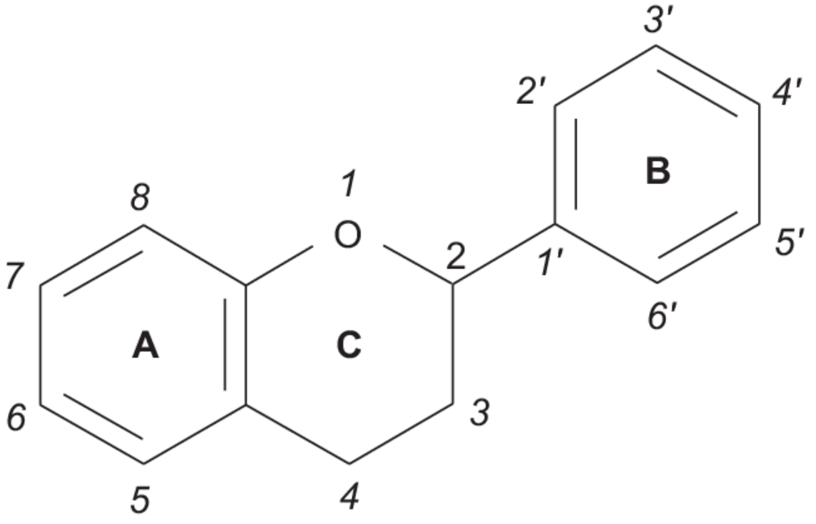

**Figure 3.** General structure of flavonoids

*Note*: Reprinted from *Wine polyphenols and promotion of cardiac health* by Cooper et al., (2004)

### 3.2.1 Flavonols

Flavonols are a group of compounds found in grape pomace, specifically in the free polyphenolic fractions, comprising approximately 8-9% of the total amount of detected phenolic compounds in grape pomace (Campos et al., 2021). In grape skins, flavonols, mainly existing in the form of glycosides, are the most abundant phenolic compounds (Yang et al., 2022). Among these flavonols, quercetin-3-O-glucuronide is the major one. Additionally, smaller amounts of quercetin-3-O-hexoside, myricetin-3-O-hexoside, and myricetin-3-O-arabinoside were also detected (Campos et al., 2021). Flavonols, also known as 3-hydroxyflavones, play a significant role in the plant kingdom, contributing to colour, taste, protection against oxidative damage, preservation of vitamins and enzymes, defence against UV radiation and parasites (Silva et al., 2023).

### 3.2.2 Flavanols

Flavanols, also known as flavan-3-ols, are derived from the flavonoid biosynthetic pathway, and commonly found in fruits and vegetables (Beres et al., 2017). These compounds are often recognised for their contribution to the taste, astringency, and colour of wine, however, a significant amount of these flavanols remains in the winemaking residue, particularly in the grape pomace (Beres et al., 2017). While the highest concentration of flavanols is found in the grape seeds, they are also present in the grape skin. According to the degree of polymerization, flavan-3-ols can be classified as catechins, oligomeric proanthocyanidins, and polymeric proanthocyanidins. The grape skin contains catechins, gallocatechins, and proanthocyanidins, while the seeds primarily contain catechins and procyanidins (Yang et al., 2022).

### 3.2.3 Anthocyanins

Anthocyanins are a group of pigments that give grapes their blue, purple, and red colour and are primarily found in the grape skin. The colour of these compounds is pH-dependent, exhibiting a red hue under strong acidic conditions and transforming into blue pigments as the pH increases (Silva et al., 2023). The levels of anthocyanins in grapes can vary widely, ranging from 30 to 750 mg/100g of fruit (Sousa et al., 2014). The most common types of anthocyanins found in grape skins are the 3-O-glycosides of malvidin, petunidine, cyanidin, peonidin, and delphinidine. Anthocyanins are widely used as food colouring additives in various food products, providing red, pink, and violet colours (Sirohi et al., 2020). However, the incorporation of anthocyanins into food matrices is limited due to their low stability during processing and storage, which is influenced by factors like pH, temperature, oxygen, pigment concentration, and water activity (Castellanos-Gallo et al., 2022). Despite their limitations, anthocyanins are widely used in the food industry, and the European Union allows their use as food dyes in various products (Arvanitoyannis et al., 2006).

## 3.3 Tannins

Tannins are a class of polyphenolic compounds that are ubiquitously found in plants. They are known for their characteristic astringent taste (Herderich and Smith, 2005). Chemically, tannins are large molecules that can be divided into two main categories: hydrolysable tannins and condensed tannins (also known as proanthocyanidins). Hydrolysable tannins are esters of gallic acid or ellagic acid with glucose or other sugar molecules. They are typically found in fruits, such as pomegranates and grapes, and can be hydrolysed by acids or enzymes to release gallic acid or ellagic acid. Condensed tannins, on the other hand, are polymers of flavan-3-ol units (catechins) and are often found in the seeds, bark, and leaves of plants. They are resistant to hydrolysis and can form complex structures (Silva et al., 2023).

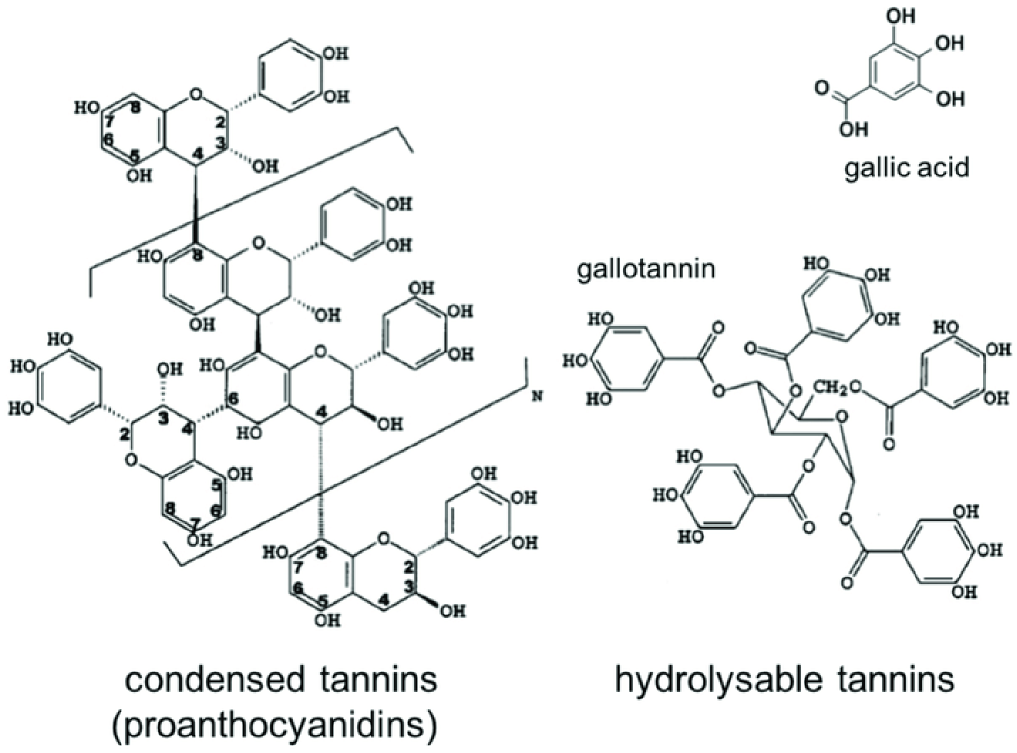

**Figure 4.** Structure of condensed and hydrolysable tannins

*Note*: Reprinted from *Unravelling the Importance of Polyphenols for Microbial Carbon Mineralization in Rewetted Riparian Peatlands* by Zak et al., (2019)

In addition to their astringency, tannins have several other properties. Due to their nature they tend to interact with proteins, forming stable complexes, which contributes to their ability to precipitate proteins and enzymes. This property makes them useful in various industrial applications, such as clarifying wines. Tannins also exhibit antioxidant activity, which is attributed to their ability to scavenge free radicals and inhibit oxidative processes (Herderich and Smith, 2005).

## 3.4 Stilbenes

Stilbenes are a class of phenols found in plants, known as phytoalexins. Among edible plants, grapes are particularly rich in stilbenes (Beres et al., 2017). Grape pomace contains various types of stilbenoids, with the most abundant being resveratrol-3-O-b-d-glucopyranoside, cis–trans resveratrol, piceatannol, and several glycosylated and isomeric forms of resveratrol dimers (Beres et al., 2017). The primary stilbene compound found in grapes, wine, and winemaking residue is resveratrol (Zhou et al., 2022). Resveratrol is a major phytoalexin that exhibits low toxicity in humans. It serves as a naturally occurring fungicide and its levels vary depending on grape maturity and variety (Sirohi et al., 2020). It has gained attention due to its potential health benefits, such as anti-cancer, cardiovascular protection, antioxidant, and anti-free radical properties (Yang et al., 2022) However, it is worth noting that the concentration of resveratrol in grape samples is generally low and often falls below the limits of quantification (Angelini et al., 2022).

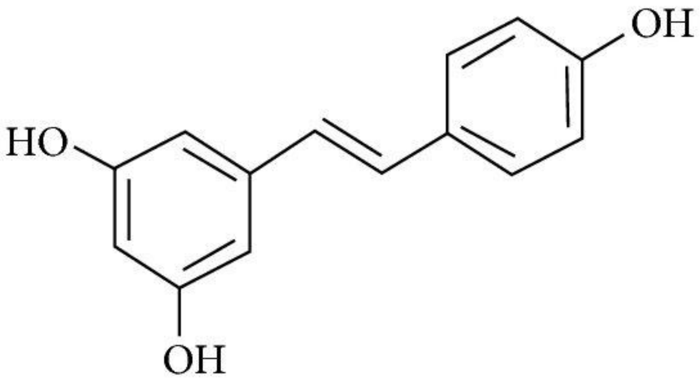

**Figure 5.** Structure of resveratrol

*Note*: Reprinted from *Polyphenols in Exercise Performance and Prevention of Exercise-Induced Muscle Damage* by Malaguti et al., (2013)

# IV. Applications of grape pomace in the food industry

In recent years, grape pomace has gained significant attention as an ingredient for fortifying various food products. Grape pomace, being rich in dietary fibre and bioactive compounds, as well as minerals and vitamins, offers a promising opportunity to enhance the nutritional profile and functional properties of different food categories. Among the studies considered for this analysis, 11 focused on the incorporation of grape pomace in bakery products, 6 investigated its potential in dairy products, 5 examined its application in meat and fish products, 2 explored its use in chocolate, and an additional 2 studies explored its potential in beverages. The selection of these studies was based on their recency, relevance, and ability to provide comprehensive information on nutritional, technological, and sensorial aspects.

## 4.1 Bakery products

Table 2 provides valuable insights into the use of grape pomace in the production of muffins, breadsticks, pasta, pizza bases, cakes, and biscuits. Red grape pomace is predominantly utilised, possibly due to its higher phenolic content. The removal of stems and seeds from the pomace is a common practice, as they might confer a bitter and astringent taste to the final product. The table also highlights the varying inclusion levels of grape pomace, with most studies incorporating 5-15% into their products. However, some studies have explored higher levels, reaching up to 25-50% of grape pomace inclusion. In the context of bakery products, the drying and milling of grape pomace into a powder or flour form is a typical approach.

**Table 2.** Effects of grape pomace addition to bakery products

| Product, Reference | Fortifying ingredient | Effects on nutritional aspects | Effects on technological characteristics | Effects on sensorial characteristics |
|---|---|---|---|---|
| **Vegan muffins (Bianchi et al., 2022)** | Distilled red grape skins powder (Cabernet)<br>0, 5, 10% | ↑ash<br>↑moisture content<br>↑dietary fibre<br>↓total starch<br>↓pH<br>↑TPC<br>↑antioxidant capacity | ↑firmness | ↑wine and fruity odour<br>↑fruity taste<br>↑astringency<br>Acceptability score - more than 6 out of 9 for all samples |
| **Muffins (Troilo et al., 2022)** | Seedless red grape pomace powder (Primitivo)<br>15% different particle size | ↑ash<br>↑lipids<br>↑proteins<br>↑carbohydrates<br>↑dietary fibre<br>↑TPC | ↓hardness<br>↑cohesiveness<br>↑stickiness in fine powders | No significant differences in the intensity of the typical odour of the commercial muffins with ↓particle size<br>↑Perceptions of toasted, must, spicy and astringent with ↓particle size<br>↑Perception of sweetness and acid with ↓particle size |
| **Muffins (Yalcin et al., 2022)** | Grape seed flour<br>7.5, 15% | ↑moisture content<br>↑lipids<br>↑proteins<br>↑TPC<br>↑antioxidant capacity | ↓hardness, chewiness (whole wheat flour and whole siyez wheat flour)<br>↑hardness, chewiness (whole oat flour) | no significant differences between muffin samples according to their crust colour, crumb colour, odour, taste, softness, moistness, crumbliness, elasticity, porosity, volume, and general preference values |
| **Gluten-free muffins (Baldán et al., 2021)** | Destemmed red grape pomace powder (Syrah)<br>0, 15, 25% | ↑ash<br>↑moisture content<br>↑lipids<br>↑proteins<br>↑dietary fibre<br>↓pH<br>↑acidity | - | - |
| **Breadsticks (Rainero et al., 2022)** | Red grape skins powder (Cabernet)<br>0, 5, 10% | ↑ash<br>↑moisture content<br>↓proteins<br>↑dietary fibre<br>↓total starch<br>↓pH<br>↑TPC<br>↑antioxidant activity<br>↓volume | ↓hardness<br>↓fracturability | ↓colour uniformity<br>↑wine odour<br>↑acid<br>↑bitterness<br>↑astringency |

TPC – total phenolic content, GPF – grape pomace flour, GPP – grape pomace powder, ↑increase, ↓decrease

**Table 2.** Effects of grape pomace addition to bakery products (continued)

| **Product, Reference** | **Fortifying ingredient** | **Effects on nutritional aspects** | **Effects on technological characteristics** | **Effects on sensorial characteristics** |
|---|---|---|---|---|
| **Pasta (Oliveira et al., 2022)** | Destemmed red grape pomace flour (Isabel)<br>0, 25, 50% | ↑ash<br>↑lipids<br>↓proteins<br>↓carbohydrates<br>↑dietary fibre<br>↓pH<br>↓water activity<br>↑TPC<br>↑antioxidant capacity | ↓hardness<br>↓firmness<br>↑cooking loss | ↓acceptance<br>50% of GPF was better evaluated than 25% for appearance and colour |
| **Durum wheat pasta (Tolve et al., 2020)** | Red grape skin powder (Corvina)<br>0, 5, 10% | ↑dietary fibre<br>↓RDS<br>↑SDS<br>↑TPC<br>↑antioxidant capacity | ↑firmness<br>↓optimum cooking time | ↓colour uniformity<br>↓aroma pasta<br>↑aroma wine, acid<br>↑astringency<br>↑graininess<br>overall quality - acceptable |
| **Pizza bases (Difonzo et al., 2023)** | Red grape skins flour<br>Red grape skins + seeds flour<br>15, 20, 25% | ↑ash<br>↓moisture content<br>↑lipids<br>↑dietary fibre<br>↑TPC<br>↑antioxidant capacity | ↑hardness<br>↑chewiness<br>↓thickness | ↑astringency =><br>↓acceptability |
| **Cakes (Nakov et al., 2020)** | Whole red grape pomace powder (Muscat Hamburg)<br>4, 6, 8, 10% | ↑ash<br>↓moisture content<br>↑lipids<br>↑proteins<br>↑dietary fibre<br>↑TPC<br>↑antioxidant capacity | ↑hardness<br>↑chewiness<br>↓springiness<br>↓cohesiveness | 4% GPP – highest marks: appearance, texture, taste, aroma, odour<br>6% GPP - outstanding for texture |
| **Biscuits (Lou et al., 2022)** | Whole red grape pomace (Cabernet Sauvignon)<br>0, 5, 10, 12.5, 15, 20% | ↑lipids<br>↑proteins<br>↑dietary fibre<br>↑TPC | ↑hardness max at 15 wt% GPP, then ↓<br>↑Chewiness max at 15% GPP, then ↓<br>↑Fracturability | chocolate colour, regular appearance, relatively smooth surface, rich fragrance, appropriate grape taste, crispy characteristic, distinct cross-section structure with small and well-distributed pores |
| **Biscuits (Fernández-Fernández et al., 2022)** | Red grape skin powder (Tannat)<br>20% | ↑TPC<br>↑antioxidant capacity | - | Acceptability: 5.1 out of 9<br>dry, adequate crunch, adequate colour to too dark, intense and persistent flavour, sweet, acid |

TPC – total phenolic content, GPF – grape pomace flour, GPP – grape pomace powder, RDS – rapidly digestible starch, SDS – slowly digestible starch, ↑increase, ↓decrease

### 4.1.1 Effects on nutritional aspects

The reviewed literature consistently indicates an increase in ash content when grape pomace is incorporated into bakery products (Baldán et al., 2021; Bianchi et al., 2022; Difonzo et al., 2023; Nakov et al., 2020; Oliveira et al., 2022; Rainero et al., 2022; Troilo et al., 2022). This increase can be attributed to the mineral composition of grape pomace, particularly its rich content in phosphorus (P), potassium (K), manganese (Mn), zinc (Zn), and iron (Fe) (Bianchi et al., 2022; Mohamed Ahmed et al., 2020; Rainero et al., 2022). Furthermore, the particle size of the grape pomace powder appears to influence the ash content. Troilo et al., (2022) found that muffins made with finer powders exhibited higher ash content, which can be explained by the release of cellular components resulting from the intensive grinding of the pomace (Troilo et al., 2022). However, the study of Lou et al., (2022) on biscuits reported no significant difference in ash content between control and sample groups, suggesting that the effects may vary depending on specific formulation and experimental conditions.

The effects of adding grape pomace to bakery products on moisture content showed varying results across the studies. Lou et al., (2022) reported no significant differences in water contents between the grape pomace groups and the control group. However, Baldán et al., (2021) observed significant differences in moisture content among gluten-free muffin samples, with muffins fortified with 25% grape pomace powder having the highest moisture value. Yalcin et al., (2022) also found that moisture contents increased with an increased amount of grape seed flour (GSF) addition, attributing the increase to the higher water absorption of fibre rich GSF. In contrast, Nakov et al., (2020) reported that the moisture content and pH of cakes decreased with increasing grape pomace addition, with the decrease potentially attributed to the inferior humidity of grape pomace. Additionally, Difonzo et al., (2023) suggested that the higher presence of dietary fibre could lead to differences in moisture content due to its interference with gluten network formation and subsequent water loss during cooking. Overall, the impact of grape pomace addition on moisture content in bakery products varied across the studies, with factors such as the type of grape pomace, concentration, and interaction with other ingredients potentially influencing the results.

Several studies have reported an increase in lipid content with the addition of grape pomace (Baldán et al., 2021; Difonzo et al., 2023; Nakov et al., 2020; Troilo et al., 2022; Yalcin et al., 2022). Furthermore, the type of oenological flour used in the production of bakery products can also influence the lipid content, with higher values observed when grape seeds were present, as reported by Difonzo et al., (2023).

Lou et al., (2022) found significantly higher crude protein levels in groups enriched with grape pomace compared to the control group. Nakov et al., (2020) attributed the higher protein content in grape pomace-enriched cakes to the use of protein-rich ingredients and the concentration of protein in grape pomace. Baldán et al., (2021), Troilo et al., (2022), and Yalcin et al., (2022) reported similar findings of increased protein levels in muffins with higher percentages of grape pomace. These changes in protein content can impact the technological and textural characteristics of the products, particularly by reinforcing the gluten matrix during baking, as a result of protein coagulation (Nakov et al., 2020). However, Oliveira et al., (2022) and Rainero et al., (2022) found that the replacement of wheat flour with grape pomace resulted in a slightly reduced protein content in their studies.

The addition of grape pomace to bakery products has consistently shown positive effects on the total dietary fibre (TDF) content of the final products. Several studies have reported a significant increase in crude fibre content with the inclusion of grape pomace flour in muffins, fortified pasta, pizza bases, cakes, and biscuits. For example, Bianchi et al., (2022), Troilo et al., (2022) and Baldán et al., (2021) found that the addition of grape pomace flour led to a substantial increase in dietary fibre content in muffins. Similarly, Lou et al., (2022), Nakov et al., (2020), Tolve et al., (2020), and Rainero et al., (2022) observed that the total dietary fibre content was positively correlated with the amount of grape pomace added to biscuits, cakes, pasta, and breadsticks. Moreover, the studies highlighted that incorporating a certain amount of grape pomace powder allowed for the labelling of the products as a "source of fibre" in accordance with the Regulation (EC) 1924/2006 (Bianchi et al., 2022; Difonzo et al., 2023; Rainero et al., 2022; Troilo et al., 2022). These findings underscore the potential of grape pomace as a functional ingredient in enhancing the fibre content and nutritional value of bakery products.

An interesting finding of Tolve et al., (2020) shows that increasing the amount of GP in the pasta dough leads to a reduction in the rapidly digestible starch (RDS) value, which represents the fraction of starch that is quickly digested, causing a rapid increase in glucose and insulin levels in the blood. Moreover, the slowly digestible starch (SDS) level, representing the fraction of starch that undergoes slow digestion and helps maintain a stable blood glucose level over time, was increased by the addition of grape pomace. This implies that incorporating grape pomace into the pasta dough may have a positive impact on the glycaemic response, potentially resulting in a lower glycaemic index and more stable blood glucose levels (Tolve et al., 2020).

The studies examining the effects of grape pomace addition to bakery products provide interesting insights into the impact on total phenolic content (TPC) and antioxidant activity. All studies found that the addition of grape pomace increased the phenolic content in pasta. Yalcin et al., (2022) reported significant differences in total phenolic contents among muffins, ranging from 353.10 ± 6.64 to 473.35 ± 0.58 mg gallic acid equivalent (GAE)/100 g of sample. Nakov et al., (2020) identified various flavonoids (catechin, epicatechin, apigenin, kaempferol, myricetin, quercetin), phenolic acids (protocatechuic acid, gallic acid, ellagic acid), and tyrosol - the only phenylethanoid detected.

The addition of grape pomace positively influenced antioxidant activity in various products, which may be associated to the TPC of the samples (Table 2). Lou et al., (2022) found that the incorporation of grape pomace increased DPPH (2,2-diphenyl-1-picrylhydrazyl) and hydroxyl radical scavenging activities. This suggests that the inclusion of grape pomace enhanced the ability of the product to neutralize or scavenge these harmful free radicals, which are known to contribute to oxidative stress and damage in the body. The use of Tannat grape skin flour also enhanced overall antioxidant capacity (Fernández-Fernández et al., 2022). However, it is important to note that the cooking process may lead to a reduction in antioxidant activity and total phenolic content (Fernández-Fernández et al., 2022; Tolve et al., 2020). Despite these losses, cooked pasta fortified with grape pomace still demonstrated a good antioxidant capacity due to the retained polyphenol compounds (Tolve et al., 2020). Overall, the studies indicate that grape pomace addition to bakery products enhances phenolic content and antioxidant activity, thereby increasing their nutritional value and potential health benefits.

### 4.1.3 Effects on technological characteristics

Troilo et al., (2022) found that varying the particle size of grape pomace powder significantly affected hardness and cohesiveness of muffins, with a lower hardness and higher cohesiveness observed in samples with smaller particle size. Yalcin et al., (2022) reported significant differences in hardness and chewiness among muffin samples, with the addition of grape seed decreasing hardness and chewiness in whole wheat and whole siyez wheat flour muffins but increasing hardness and chewiness in whole oat flour muffins. Hardness is the force needed for sample deformation (Lou et al., 2022; Zhang et al., 2020), while chewiness depicts the force required to transform a sample from a chewable state to a swallowable state (Lou et al., 2022). Rainero et al., (2022) found that the addition of grape pomace reduced the hardness and fracturability of breadsticks, possibly due to a damaged gluten protein network. Oliveira et al., (2022) observed a reduction in hardness in functional pasta with higher fibre content, likely due to water absorption competition between fibres and starch. Difonzo et al., (2023) noted that the addition of grape pomace affected hardness and chewiness of pizza bases more significantly, potentially due to the richness of dietary fibre and absence of gluten interfering with gluten network formation. Lou et al., (2022) indicated that hardness increased with the addition of grape pomace in biscuits, and it should be minimised to ensure acceptability. Nakov et al., (2020) reported that the addition of grape pomace increased hardness and chewiness while slightly reducing springiness and cohesiveness.

Bianchi et al., (2022) observed an increase in firmness in vegan muffins due to the addition of grape pomace, which diluted the gluten in the dough, potentially reducing the gas-capturing ability and increasing the density of the muffins. Similarly, Tolve et al., (2020) reported that the fortification of spaghetti with grape pomace led to an increase in firmness.

The effects of grape pomace addition on the fracturability of food products have shown some contradictory findings. Fracturability refers to the force at which a sample cracks during the first compression (Lou et al., 2022; Mohsen et al., 2009). In the case of breadsticks, Rainero et al., (2022) found that the addition of grape pomace powder resulted in a decrease in both hardness and fracturability. They attributed this effect to a damaged and unconstructed gluten protein network caused by the presence of grape pomace. On the other hand, Lou et al., (2022) reported an increase in fracturability with increasing GPP content in biscuits. These conflicting results could be influenced by factors such as the specific food product, the level of grape pomace incorporation, and the impact on the structure of the gluten protein network. Further research is needed to fully understand the relationship between grape pomace addition and fracturability in different bakery products.

Several studies found that the addition of grape pomace powder to breadsticks resulted in a significant decrease in pH values compared to the control samples (Table 2).

Rainero et al., (2022) explains that the acidic conditions created by GPP fortification could cause the dough to become more tenacious and less extensible. This change in rheological properties affected the leavening and aeration properties of the dough, leading to a reduction in volume of the fortified breadsticks. The researchers also noted a strong negative correlation between the reduction in volume and the fibre content of the breadsticks, suggesting that the fibre content of GPP played a role in modifying the dough's rheological properties and its ability to hold air bubbles during leavening.

In the study by Troilo et al., (2022), it was found that the specific volume of muffins decreased as the particle size of grape pomace decreased. This decrease in specific volume suggests that the muffins became more compact. The authors attributed this effect to the different consistency and viscosity of the doughs containing different particle sizes. It is likely that the doughs with finer particles had a reduced ability to retain air bubbles and carbon dioxide, leading to a denser and less voluminous muffin structure.

#### 4.1.4 Effects on sensorial characteristics

Colour is an important attribute that significantly influences the market acceptance of baked goods. The inclusion of grape pomace powder did not visually alter the colour uniformity and porosity of vegan muffins (Bianchi et al., 2022). In the study by Troilo et al., (2022) it was found that the crust colour of muffins was more intense when using smaller particle sizes of grape pomace powder, likely due to a more even mixing of the GPP with other ingredients. A similar trend was observed in pizza bases, where the appearance descriptors showed higher scores for crust colour intensity compared to the control (Difonzo et al., 2023). The crumb colour intensity of pizza bases was also influenced by the percentage of grape pomace replacement, with higher levels of GPP resulting in a more intense colour (Difonzo et al., 2023). This observation is consistent with a previous study on biscuits (Lou et al., 2022). In the case of biscuits, the colour score slightly increased with the inclusion of GPP, leading to a favourable chocolate colour. Additionally, the colour of pasta enriched with grape pomace was perceived as more attractive and associated with a healthier product by consumers (Oliveira et al., 2022).

Aroma is another important sensorial attribute. The addition of distilled grape pomace powder to muffins significantly improved the wine and fruity odours, which are characteristic of the Cabernet variety used in the study (Bianchi et al., 2022). In another study on muffins, Troilo et al., (2022) found that the intensity of certain odours, such as toasted, must, spicy, and astringent, increased with decreasing particle size of grape pomace powder. This observation could be attributed to a lower content of dietary fibre in finer particles. The inclusion of grape pomace in breadsticks and pasta has also been associated with enhanced wine odour, as reported by Rainero et al., (2022) and Tolve et al., (2020). These findings suggest that the aroma profile of baked goods can be influenced by the inclusion of grape pomace, with specific effects observed based on the particle size and type of grape pomace powder used.

The inclusion of distilled grape pomace powder in muffins had a statistically significant effect on taste, particularly in terms of fruitiness, which was positively correlated with the addition of grape pomace (Bianchi et al., 2022). The perception of sweetness and acid in muffins was also influenced by the particle size of grape pomace powder, with increasing intensity as the particle size decreased (Troilo et al., 2022). The acidic taste was perceived more in fortified breadsticks and innovative pizza bases (Difonzo et al., 2023; Rainero et al., 2022). However, global flavour, sweetness, and saltiness were not significantly affected by the inclusion of grape pomace in the studies mentioned. The presence of tannins in grape pomace contributed to increased astringency in the fortified samples. Astringency was found to be enhanced in breadsticks and pizza bases formulated with grape pomace, particularly due to the presence of grape seed flour and its high content of flavan-3-ols (Difonzo et al., 2023; Rainero et al., 2022). The astringency is attributed to the precipitation of proline-rich salivary proteins in the mouth caused by phenolic compounds present in grape seeds. Higher perception of astringency has been reported to reduce the acceptability of biscuits (Difonzo et al., 2023).

The fortification of baked goods with distilled grape pomace powder (DGPP) did not influence elasticity, mellowness, adhesiveness, and hardness in muffins (Bianchi et al., 2022). Fortified breadsticks showed decreased friability with the increasing amount of grape pomace powder added (Rainero et al., 2022). The addition of fibre, such as grape pomace, can weaken the dough structure and reduce the sensorial firmness of the final product (Oliveira et al., 2022). Texture attributes such as humidity and softness were affected in fortified pizza bases compared to the control. The fortified samples appeared drier, and softness varied depending on the type of grape pomace used. The use of the mix off grape skins and seeds flour made the samples softer, likely due to the high lipid content in grape seeds (Difonzo et al., 2023).

Bianchi et al., (2022) found that the addition of grape pomace to muffins did not significantly impact overall acceptability, with scores exceeding the threshold value of 5. Similarly, Yalcin et al., (2022) reported good sensory acceptability of muffins fortified with grape seed flour. Troilo et al., (2022) noted a greater preference for muffins formulated with coarse particle sizes, suggesting that it had a lower impact on taste, smell, and overall structure. Rainero et al., (2022) reported similar overall acceptability between control breadsticks and those fortified with grape seed flour, although the latter had slightly lower ratings. Tolve et al., (2020) found that no matter the amount of grape pomace added, the fortified pasta was judged as acceptable by the panellists. In contrast, Oliveira et al., (2022) found that the control pasta had higher acceptance ratings, indicating that an optimal concentration of grape pomace should be determined to minimize adverse effects on overall impression and purchase intention. Lou et al., (2022) indicated that biscuits fortified with grape pomace at levels below 12.5 wt% were not substantially different in acceptability from the control group. Fernández-Fernández et al., (2022) noted that TGS biscuits had an acceptability score of 5.1 out of 9, suggesting further studies to improve acceptability, possibly by complementing with inulin to mask off-flavours. Nakov et al., (2020) found that cakes with 4% grape pomace received the highest evaluation marks for all sensory parameters, while the cakes with 6% grape pomace was outstanding in terms of texture, and the control cake received slightly lower scores. Overall, the studies indicate that the acceptability of bakery products fortified with grape pomace can vary depending on factors such as the type and amount of pomace used, particle size, and formulation. However, many products achieved acceptable ratings, suggesting that the incorporation of grape pomace can be successful in maintaining overall product quality and consumer acceptance.

## 4.2 Dairy products

Table 3 provides data on the utilisation of grape pomace in the production of yoghurt, kefir, and cheese. As in the case of bakery products (Table 2), red grapes were preferred due to their high content of phenolic compounds. In the studies examining the fortification of yoghurt, various grape-derived ingredients were utilised, including grape skin extract (Olt et al., 2022), grape skin powder (Fernández-Fernández et al., 2022), and grape pomace extract (Iriondo-DeHond et al., 2020). Kefir production, on the other hand, incorporated grape seed extract as a fortifying agent (Carullo et al., 2022). In the case of cheese production, both grape skin powder (Gaglio et al., 2021) and whole grape pomace powder (Lucera et al., 2018) were employed for fortification purposes. The table also showcases the diverse levels of grape pomace extract inclusion, with most studies incorporating 0.5-1% into their products. In the cases where pomace powder was employed, concentrations of 0.5, 1, and 5% were utilised.

### 4.2.1 Effects on nutritional aspects

According to Gaglio et al., (2021), the incorporation of grape pomace in cheese formulations leads to a decrease in fat content due to the lower lipid content of grape skins compared to milk. Consequently, this results in an increase in protein content in the enriched cheeses. Additionally, the ash content in the cheeses tends to increase, which can be attributed to the higher ash level present in grape pomace compared to milk.

The addition of grape pomace to dairy products has been found to increase the total phenolic content (TPC) in various studies. Olt et al., (2022) observed an increase in TPC after adding encapsulated grape skin extract to yoghurt, indicating a contribution of polyphenols from the winemaking by-product. Iriondo-DeHond et al., (2020) also found that the TPC of control yoghurts significantly increased with the addition of winery by-product extracts, and grape skin yoghurts had higher TPC compared to yoghurts containing grape pomace and seed extracts. In the case of kefir, Carullo et al., (2022) noted a significant increase in total phenolic equivalents with the addition of grape seed extract, with further enhancement (+49%) when combined with inulin. These findings highlight the potential of grape pomace as a source of phenolic compounds in dairy products, with differences observed based on the fraction of grape used and the specific product formulation.

**Table 3.** Effects of grape pomace addition to dairy products

| Product, Reference | Fortifying ingredient | Effects on nutritional aspects | Effects on technological characteristics | Effects on sensorial characteristics |
|---|---|---|---|---|
| **Yoghurt (Olt et al., 2022)** | Red grape skins encapsulated ethanolic extract<br>0.5%, 1%<br>(Tannat) | ↑TPC<br>↑antioxidant capacity | ↓L* and b*<br>↑a* | - |
| **Yoghurt (Fernández-Fernández et al., 2022)** | Red grape skins powder<br>0.5%<br>(Tannat) | No significant antioxidant capacity<br>↓ ROS formation<br>↓ NO formation<br>↑ α-glucosidase inhibition capacity | No significant effect on pH, acidity | Acceptability: 6.3 out of 9<br>suitable colour and adequate consistency, soft texture, natural flavour, smooth, rich flavour, adequate creaminess, little to adequate sweet |
| **Yoghurt (Iriondo-DeHond et al., 2020)** | Food-grade commercial extracts (grape pomace, seed, skin)<br>0.5% | ↑TPC<br>↑antioxidant capacity<br>↑ α-glucosidase inhibition capacity | ↑firmness<br>↑consistency<br>↑moisture content<br>↑syneresis<br>No significant effect on pH | Acceptability: 6.33 - 6.37 out of 9<br>↑acceptability - skins |
| **Kefir (Carullo et al., 2022)** | Inulin-grafted white grape seed extract<br>(Pecorello)<br>1% | ↑TPE<br>↑antioxidant capacity | - | - |
| **Ovine stretched cheese (Gaglio et al., 2021)** | Red grape skins powder<br>1%<br>(Nero d'Avola) | ↑ash<br>↑protein<br>↓fat<br>↑antioxidant activity (after digestion) | ↓L* and b*<br>↑a*<br>↓pH<br>↑hardness<br>↑lipid oxidation<br>↑friability<br>↑adhesiveness<br>↑humidity | ↑odour and aroma intensity<br>↑acid perception<br>↑fibre sensation<br>↓sweetness |
| **Spreadable cheese (Lucera et al., 2018)** | White and red whole grape pomace powder<br>5% | ↑TPC<br>↑TFC<br>↑antioxidant activity | ↓pH<br>↓moisture<br>↓spreadability | ↑overall intensity<br>↑acid taste<br>↑astringency |

TPC – total phenolic content, TFC – total flavonoid content, TPE – total phenolic equivalents, L*- lightness, a*- redness, b*- yellowness, ↑increase, ↓decrease

The findings from multiple studies indicate that the incorporation of grape pomace can lead to increased antioxidant capacity (Table 3). Olt et al., (2022) demonstrated that the addition of encapsulated extract to yoghurt significantly increased its antioxidant capacity compared to the base formulation. Similarly, Iriondo-DeHond et al., (2020) reported that the inclusion of winery by-product extracts in yoghurts resulted in significantly increased antioxidant capacity compared to the control yoghurts. Moreover, yoghurts containing grape skin extracts demonstrated a higher antioxidant capacity than the ones enriched with pomace or seeds, which is in line with the TPC determined previously. Carullo et al., (2022) found that the addition of inulin-grape seed extract conjugate to fermented milk improved antioxidant performance, showing higher antioxidant activity compared to using grape seed extract alone. Gaglio et al., (2021) also reported increased antioxidant activity and lipoperoxyl radical scavenger capacity in the digested cheeses, suggesting that degradation of the dairy matrix is necessary to release the polyphenols from the grape pomace. The study conducted by Fernández-Fernández et al., (2022), initially, showed no significant differences in antioxidant capacity. However, over time, the antioxidant activity of the enriched yoghurt increased compared to the control. The study suggests that this increase could be attributed to bacterial metabolic activity and the release of bioactive peptides through lactic fermentation proteolysis.

Besides the antioxidant activity, products enriched with grape pomace have demonstrated activities such as α-glucosidase inhibition, reactive oxygen species (ROS) and nitric oxide (NO) inhibition. Fernández-Fernández et al., (2022) found that yoghurt containing red grape skin powder exhibited higher α-glucosidase inhibitory capacity compared to the control, indicating its potential to regulate blood glucose levels. Iriondo-DeHond et al., (2020) also observed that the inhibition of α-glucosidase activity was significantly higher in yoghurts containing grape skin and grape pomace extracts compared to control yoghurts. They suggested that the phenolic compounds present in grape skins contributed to this effect.

The addition of grape pomace to dairy products has demonstrated promising effects on cell health and inflammation. In healthy human colon cells, the digested yoghurt containing Tannat grape skin anthocyanins exhibited a significant inhibition of ROS formation, indicating its potential antioxidative properties (Fernández-Fernández et al., 2022). Furthermore, the Tannat grape skin yoghurt digest showed a marked reduction in nitric oxide formation in lipopolysaccharide-induced macrophages, indicating its anti-inflammatory potential (Fernández-Fernández et al., 2022).

### 4.2.2 Effects on technological characteristics

The impact of adding grape pomace to dairy products on pH and titratable acidity has been described by multiple sources. Carullo et al., (2022) observed an increase in pH when grape seed extract was added to kefir. In the study by Gaglio et al., (2021), experimental curds with grape skin powder exhibited lower pH values compared to the control curds. This was attributed to the presence of organic acids, such as tartaric acid, malic acid, and citric acid, in the grape skins. Lucera et al., (2018) also reported a decrease in pH when red and white grape pomace powders were added to the samples, indicating an acidic shift in the dairy products.

However, in the study by Fernández-Fernández et al., (2022), yoghurt formulations with and without the addition of Tannat grape skin powder showed no significant variation in pH or titratable acidity during the study period. Similarly, Iriondo-DeHond et al., (2020) found that the addition of winery by-product extracts did not significantly alter the pH or titratable acidity of yoghurt. The discrepancies in results could be attributed to differences in formulations, including the quantity and intrinsic pH of grape extracts or flour, probiotic strains' metabolic activity, and the interaction with other ingredients like sucrose, inulin, and fructo-oligosaccharides.

The addition of grape pomace to dairy products, specifically yoghurt, has been found to have significant effects on syneresis, which refers to the separation of whey from yoghurt during storage (El Bouchikhi et al., 2019). In a study by Iriondo-DeHond et al., (2020), it was observed that yoghurt fortified with winery by-product extracts showed a significant increase in syneresis during the last two weeks of storage. This increase in syneresis can be attributed to the high amount of polyphenols present in the food matrix. According to the protein-polyphenol interaction model (Siebert et al., 1996), the incorporation of polyphenols leads to an increase in particle-particle junctions within the gel structure, resulting in shrinkage of the network and the expulsion of interstitial liquid. Furthermore, the timing of adding the winery by-product extracts to the yoghurt production process was found to impact the syneresis rates. When the extracts were added to the milk before fermentation, greater syneresis rates were observed compared to when they were added after the yoghurt gel was formed (Iriondo-DeHond et al., 2020).

The effects of adding grape pomace to dairy products have shown some variations in moisture content. When incorporating grape pomace in spreadable cheese, Lucera et al., (2018) observed a reduction in moisture compared to the control. The authors suggest that the addition of by-product flours increased the total solids content in the formulation, leading to a decrease in moisture percentage. On the other hand, in the case of grape skin yoghurt, the moisture content was significantly higher compared to the control yoghurt during storage (Iriondo-DeHond et al., 2020). The authors speculate that the contrasting results could be attributed to different interactions between grape skin polyphenols and other components in the matrix.

The inclusion of winery by-product extracts in yoghurts resulted in a tendency towards increased firmness and consistency compared to control yoghurts (Iriondo-DeHond et al., 2020). Grape pomace inclusion in cheese led to an increase in hardness, as observed in the resistance to compression. This effect is attributed to the impact of grape pomace on increasing dry matter or reducing fat content in experimental cheeses (Gaglio et al., 2021). Spreadability, another important textural attribute, showed variations with the addition of grape pomace to cheese (Lucera et al., 2018). The control sample exhibited high spreadability, while the sample with grape pomace incorporation was less spreadable. This could be attributed to changes in moisture content and increased total solid content resulting from the incorporation of grape pomace flour (Lucera et al., 2018).

The addition of grape pomace to dairy products has shown notable effects on their colour characteristics. Samples containing grape pomace extract exhibited lower luminosity (L*) values compared to those without the extract. This can be attributed to the presence of anthocyanins in the extract, which impart a darker colour to the yoghurt. The “a” value, representing the red-green axis, was positively influenced by the incorporation of the extract, indicating a trend towards violet coloration in the yoghurt. Furthermore, a significant decrease was observed in parameter "b," representing the yellow-blue axis, between samples with and without the grape pomace (Olt et al., 2022). Similarly, when grape pomace was incorporated into cheese production, a significant alteration in both external and internal colour indexes was observed. The experimental cheeses exhibited a distinct pink colour, accompanied by a noticeable increase in redness and a decrease in lightness and yellowness (Gaglio et al., 2021). These findings highlight the substantial impact of grape pomace on the colour profiles of dairy products, showcasing shifts towards darker shades and altered colour indexes. However, it should be noted that the studies involving white grape pomace did not provide specific findings regarding colour changes. It would be beneficial to conduct measurements on the colour parameters of white pomace to assess whether any appearance alterations occur.

### 4.2.3 Effects on sensorial characteristics

The sensory attributes and acceptability of adding grape pomace to dairy products were evaluated in several studies. In a study by Iriondo-DeHond et al., (2020), consumers evaluated all yoghurt formulations similarly regarding characteristics such as smell, flavour, texture, and overall acceptability. However, significant differences were observed in appearance, with the control and grape skin yoghurts scoring higher than the grape pomace and seed yoghurts. The familiarity of the control yoghurt and the attractive colour provided by grape skin extract contributed to their higher visual acceptability. The study by Olt et al., (2022) also highlighted the characteristic violet/purple colour observed in yoghurts with grape pomace extract, suggesting the extract as a natural colorant for the development of novel yoghurts. Fernández-Fernández et al., (2022) evaluated TGS yoghurt and reported an acceptability rating of 6.3 out of 9, describing it as possessing suitable colour, adequate consistency, soft texture, natural flavour, and adequate creaminess.

In terms of cheese, Gaglio et al., (2021) found that the addition of grape pomace increased odour and aroma intensity, acid perception, fibre sensation, friability, adhesiveness, and humidity, while negatively influencing sweet and hardness attributes. The addition of grape pomace powders to spreadable cheese led to higher acid values and a greater astringent sensation, possibly due to the presence of polyphenols, such as tannins, found in grape skins (Lucera et al., 2018).

Overall, the addition of grape pomace to dairy products had varying effects on nutritional, technological and sensorial attributes. The presence of polyphenols in grape pomace contributed to astringent sensations and higher acidity in cheese. While some attributes were positively influenced, such as odour, aroma, and colour, others were affected negatively, such as spreadability and hardness. However, the incorporation of grape pomace extracts was seen as a potential strategy to improve sensory acceptability and enhance the nutritional value of dairy products.

## 4.3 Meat and fish products

The studies investigating the fortification of meat and fish products with grape pomace aimed to assess the impact on shelf life, storage stability, and lipid oxidation. The fortification approaches included adding grape pomace flour to the recipe (Abdelhakam et al., 2019; Cilli et al., 2020), incorporating grape pomace extract into the product (Pereira et al., 2022), or microencapsulating the extract and adding it to the recipe (Carpes et al., 2020; dos Santos Silva et al., 2022). The effects on nutritional, technological and sensorial aspects are summarized in Table 4.

**Table 4.** Effects of grape pomace addition to meat and fish products

| **Product, Reference** | **Fortifying ingredient** | **Effects on nutritional aspects** | **Effects on technological characteristics** | **Effects on sensorial characteristics** |
|---|---|---|---|---|
| **Beef hamburger patty (Pereira et al., 2022)** | Red grape pomace extract (skins, seeds) (Merlot)<br>0%, 2% and 4% | ↑TPC<br>↑antioxidant activity | ↓L*, a*, b*<br>↓pH<br>↓cooking yield | ↓texture, taste, overall acceptability<br>↑hardness<br>↑springiness<br>↑gumminess<br>↑chewiness |
| **Beef burger (dos Santos Silva et al., 2022)** | Lyophilised and microencapsulated red grape pomace extract<br>0.1%, 0.67%<br>(Isabella) | ↑TPC<br>↑antioxidant capacity<br>↓lipid oxidation | ↑L*<br>↓a*<br>↑b* | - |
| **Salmon burger (Cilli et al., 2020)** | Red grape pomace flour (skins, seeds) (Isabel)<br>1, 2% | ↓lipid oxidation | ↓L*, a*, b*<br>↓moisture content | ↓appearance, colour, overall quality<br>↓flavour, texture<br>no negative effects on odour<br>acceptability > 6/9 |
| **Chicken pâté (Carpes et al., 2020)** | Lyophilised and microencapsulated red grape pomace extract<br>(Bordeaux) | ↑TPC<br>↑antioxidant capacity<br>↓lipid oxidation | - | - |
| **Beef hamburger (Abdelhakam et al., 2019)** | Red grape pomace flour (skins and seeds)<br>2, 4%<br>(Red Globe1) | ↓lipid oxidation<br>↓microbial growth | ↓water holding capacity<br>↑cooking yield<br>↓pH | - |

TPC – total phenolic content, L* - lightness, a*- redness, b*- yellowness, ↑- increase, ↓- decrease

### 4.3.1 Effects on nutritional aspects

It has been established previously that grape pomace contains high levels of phenolic compounds which attributes an increased antioxidant activity to the fortified product. This is in line with the studies on meat and fish presented in Table 4. The addition of grape pomace to meat and fish products demonstrated inhibitory effects on lipid oxidation, a key factor in maintaining product quality. In the study by dos Santos Silva et al., (2022), treatments with grape pomace extracts showed significant reductions in malondialdehyde (MDA) levels, a well-established marker of lipid peroxidation (Zeb and Ullah, 2016), indicating its effective inhibition. The formulation with the addition of synthetic antioxidant exhibited the highest MDA levels throughout storage, while the lyophilised and microencapsulated phenolic extract treatments showed stabilisation or lower MDA levels. Similarly, Cilli et al., (2020) observed that the addition of grape pomace extract resulted in markedly reduced levels of thiobarbituric acid reactive substances (TBARS) compared to the control. TBARS is widely recognized as a standard marker for assessing lipid peroxidation-induced oxidative stress (Zeb and Ullah, 2016). Thus, the observed inhibition of TBARS demonstrates the effectiveness of grape pomace extract in effectively delaying lipid oxidation during frozen storage. Carpes et al., (2020) also reported that chicken pâté treated with lyophilised and microencapsulated grape pomace extracts had significantly lower TBARS values throughout storage compared to the control, showing the ability of grape pomace to inhibit lipid oxidation.

The study by Abdelhakam et al., (2019) also investigated the effect of incorporating red grape pomace flour on the microbial growth of beef hamburger during frozen storage. The results indicated that the microbial growth increased with longer storage time for all treatments. However, the incorporation of red grape pomace powder in beef hamburger resulted in a gradual decrease in total bacterial count compared to the control. This reduction in bacterial count was attributed to the higher content of phenolic compounds in beef hamburger incorporated with winery by-products.

### 4.3.2 Effects on technological characteristics

The effects of adding grape pomace to meat and fish products were evaluated in terms of pH, water holding capacity (WHC) and cooking yield. Pereira et al., (2022) found that as grape pomace was added to patties, the pH values decreased stepwise from 5.83 to 5.74, and to 5.68 for inclusion levels of 0%, 2%, and 4%, respectively. Similarly, Abdelhakam et al., (2019) observed a decrease in pH as red grape pomace was incorporated into beef hamburgers. The control burger had a pH of 6.68, which decreased to 6.41 and 6.22 when 2% and 4% grape pomace were added, respectively. This pH reduction could be attributed to the low pH of the fermented pomace used.

In the study by Abdelhakam et al., (2019), it was found that the addition of red grape pomace powder (RGPP) to beef hamburger negatively affected the water holding capacity (WHC). As the level of RGPP increased, the WHC decreased, indicating a lower water-holding capacity. This reduction in WHC was attributed to protein denaturation, which reduced its ability to hold water. Consequently, the cooking yield of beef hamburger decreased along the storage period. However, when compared to the control treatment, beef hamburger enriched with RGPP had higher cooking yield values, suggesting that the fibre components of RGPP influenced the cooking yield by reducing water loss during cooking (Abdelhakam et al., 2019).

In contrast, Pereira et al., (2022) observed that grape pomace patties had lower cooking yield compared to control patties, regardless of pomace concentration. The difference in results could be explained by the pH of the control patties, which was higher by approximately 1 pH unit in the study of Abdelhakam et al., (2019). The incorporation of other ingredients, such as salt, pepper, and cumin, in the hamburgers of Abdelhakam et al., (2019) might have also influenced their higher cooking yield compared to pomace-enriched patties (Pereira et al., 2022).

The addition of grape pomace to meat and fish products has been found to have significant effects on instrumental colour. Studies have shown that grape pomace, rich in phenolics, contributes to a darker colour in fortified samples. Anthocyanins, water-soluble pigments responsible for red, purple, and blue colours in plants, are particularly influential in this regard (Silva et al., 2016). When comparing fortified patties with control patties, fortified patties exhibited lower L* (lightness), a* (redness), and b* (yellowness) values (Cilli et al., 2020; Pereira et al., 2022).

The influence of cooking and storage time on colour along with different formulations involving grape pomace were also investigated. In the study by dos Santos Silva et al., (2022), formulations with the addition of synthetic antioxidant (SEB), lyophilized phenolic extract (LEB), and microencapsulated phenolic extract (MEB) were analysed. After cooking, it was observed that the samples experienced higher luminosity and a loss of red colour intensity, potentially due to cooking temperature, the degradation of myoglobin, and a partial loss of anthocyanins (dos Santos Silva et al., 2022). The freeze-dried and microencapsulated extracts maintained stability in luminosity, whereas the synthetic antioxidant treatment showed significantly higher luminosity. The SEB and LEB treatments showed decreases in red colour intensity. The MEB treatment, on the other hand, maintained red colour stability, indicating that microencapsulation protected anthocyanins. The SEB treatment demonstrated a greater tendency toward yellowing, while the LEB and MEB treatments maintained colour stability.

### 4.3.3 Effects on sensorial characteristics

The effects of adding grape pomace to meat and fish products were evaluated in two studies (Table 4). In the study by Pereira et al., (2022) on hamburger patties, no significant difference was found between control and pomace patties for flavour, juiciness, and colour. However, the pomace patties received lower scores for texture, taste, and overall acceptability. The addition of grape pomace to hamburger patties at 2% and 4% increased the values of hardness, springiness, gumminess, and chewiness compared to control patties, with no difference detected for cohesiveness. The lower textural value was attributed to higher hardness, while the lower taste score was linked to the low patty pH. The combination of firmer texture, sour taste, and dark appearance contributed to the lower overall acceptability. These findings suggest that grape pomace can influence the sensory attributes and texture profile of meat products.

In the study by Cilli et al., (2020) on salmon burgers, the addition of grape pomace flour (GPF) resulted in decreased liking scores for appearance, colour, and overall quality compared to the negative control or samples with a synthetic antioxidant. Higher amounts of GPF generally achieved lower scores for flavour and texture attributes. Some consumers reported that the characteristic fish flavour was masked in the samples containing GPF. However, despite these effects, the salmon burgers with GPF still received sensory scores above 6.0 out of 9 for all assessed attributes. The addition of GPF had no negative effects on odour. The study suggests that providing information on the functional properties associated with bioactive compounds can improve the perception of healthy food and mitigate negative sensory attributes.

Overall, the addition of grape pomace resulted in increased total phenolic content (TPC) and antioxidant activity, indicating a potential boost in the functional properties of the fortified products. Moreover, grape pomace demonstrated inhibitory effects on lipid oxidation in meat and fish products, contributing to their storage stability. However, the addition of grape pomace significantly influenced the colour parameters of the products, which may raise concerns regarding consumer acceptability. Additionally, texture alterations were observed, highlighting a potential challenge in terms of sensorial attributes. Further analysis and optimization are necessary to strike a balance between the positive effects on nutritional quality and the potential impact on sensory attributes when incorporating grape pomace into meat and fish products.

## 4.4 Chocolate

Grape pomace was incorporated into the formulation of chocolate and the effects on nutritional and technological aspects are summarized in Table 5. The fortification approach included adding red grape pomace powder to the recipe at different quantities, enabling an assessment of its impact on nutritional and technological aspects of chocolate.

**Table 5.** Effects of grape pomace addition to chocolate

| Product, Reference | Fortifying ingredient | Effects on nutritional aspects | Effects on technological characteristics |
|---|---|---|---|
| **Chocolate (Bursa et al., 2022)** | Red grape skins powder (Cabernet Sauvignon)<br>0 – 15% | ↑TPC<br>↑resveratrol<br>↓sugar content | ↑particle size<br>↑plastic viscosity<br>↑yield stress<br>↓cost |
| **White chocolate (Altinok et al., 2022)** | Red grape pomace (seeds and skins) powder<br>(Kalecik Karası)<br>10, 20, 30% | ↑TPC<br>↓sugar content | ↑particle size<br>↓specific surface area<br>↑moisture content<br>↓plastic viscosity<br>↓yield stress<br>↓L* and b*<br>↑a*<br>↑hardness - 10% GPP<br>↓hardness - 20 and 30% GPP |

TPC – total phenolic content, L* - lightness, a* - redness, b* - yellowness, GPP – grape pomace powder, ↑- increase, ↓- decrease

### 4.4.1 Effects on nutritional aspects

The effects of adding grape pomace to chocolate were investigated in two studies (Table 5). Bursa et al., (2022) found that the total phenolic content (TPC) and resveratrol levels were highest in samples with higher concentrations of grape skin powder (12.989% and 14.996 respectively). The addition of winemaking by-products also led to decreases in sugar content, demonstrating the potential to develop a functional compound chocolate with an enhanced nutritional profile.

Altınok et al., (2022) focused on the addition of grape pomace powder (GPP) to white chocolate. Different amounts of GPP (10, 20, and 30 g/100 g) were added to reduce sugar content and add functional quality. Only the sample with 10.0 g GPP/100 g chocolate was analysed for the bioavailability of TPC. The in vitro digestion analysis demonstrated that the use of GPP in white chocolate increased the amount of total phenolic substances detected. The study also found that the bioavailability of TPC significantly increased in white chocolate with the addition of GPP. These results suggest that incorporating GPP in white chocolate not only reduces sugar content but also enhances the presence and bioavailability of phenolic compounds.

### 4.4.2 Effects on technological characteristics

The particle size plays a crucial role in the textural, rheological, colour, water activity, and melting properties of chocolate (Bursa et al., 2022). Coarser particles can result in a sandy structure and affect mouthfeel, while smaller particles contribute to flow properties (Bursa et al., 2022). Bursa et al. (2022) found that an increase in dried grape pomace (DGP) content led to a significant increase in particle size values, indicating that DGP can act as a bulking agent in the chocolate formulation. This was further supported by Altınok et al. (2022), who reported an increase in particle size distribution and a decrease in specific surface area with the addition of grape pomace powder (GPP) in white chocolate samples. The optimal concentration of GPP for controlling particle size was found to be 10%, as smaller particles positively impacted sensory properties and flow behaviour.

Bursa et al., (2022) found that as the amount of grape skin powder increased in chocolate formulations, the plastic viscosity value also increased, indicating a thicker consistency. Moreover, the decrease in milk powder and increase in grape skins and sugar content led to an increase in yield stress, which is the force required to initiate flow (De Graef et al., 2011). However, within a maximum inclusion of 10% DGP, no major differences in plastic viscosity and yield stress values were observed compared to conventional chocolate (Bursa et al., 2022). Altınok et al., (2022) observed that the fat content of white chocolate increased with higher concentrations of grape pomace powder, resulting in a decreased viscosity and improved flow. This could be attributed to the presence of seeds in the pomace, in contrast to the previous study, where only grape skins were used (Table 5). Additionally, the particle size of chocolate affected its flow behaviour, with finer particles leading to increased viscosity due to the need for a higher total specific surface area to cover free fat (Altınok et al., 2022).

The hardness of chocolate enriched with 10% GPP (GPP10) was significantly higher than the control group, while samples containing 20% and 30% had significantly lower values (Altınok et al., 2022). The moisture content of the grape pomace was identified as a potential factor affecting hardness, with increasing moisture content leading to lower hardness values. Particle size also played a role, as increasing particle size was associated with decreased chocolate hardness. The presence of oil in the grape seeds within the grape pomace composition contributed to decreased hardness values, potentially causing issues with tempering and uniform crystallization. However, the GPP10 group demonstrated increased hardness, which could be attributed to the higher fibre content and a more rigid structure without negatively affecting the fat content and crystallisation.

The addition of grape pomace powder to white chocolate had a significant impact on the colour properties, as reported by Altınok et al., (2022). In comparison to the control sample, the chocolates containing GPP exhibited lower L* values, indicating a darker surface as the concentration of GPP increased. The a* value of the chocolates increased with the addition of GPP, while the b* value, representing the yellow colour, was suppressed and decreased significantly with higher GPP concentrations. The alterations in colour can be influenced by the composition and processing techniques of the chocolates.

Although the studies listed in this paper did not conduct any sensory analysis, it is important to recognize that the previously mentioned characteristics could potentially have a negative impact on the consumer acceptance of functional chocolate. Therefore, future studies should consider incorporating sensory analysis to gain a more comprehensive understanding of the consumer perception and acceptability, enabling further refinement and optimisation of functional chocolate formulations.

## 4.5 Beverages

The fortification of beverages with grape pomace extract (GPE) presents an innovative approach to enhance their nutritional value and functional properties. Several studies have investigated the incorporation of grape pomace extract into different beverages, including beer and coconut water, as reported in Table 6. In these studies, GPE was utilized as a rich source of bioactive compounds. For beer fortification, a concentration of 10-20% GPE was employed, while coconut water was fortified with 2% GPE, taking an additional step by microencapsulating the grape pomace extract, potentially providing controlled release and improved stability.

**Table 6.** Effects of grape pomace addition to beverages

| Product, Reference | Fortifying ingredient | Effects on nutritional aspects | Effects on technological characteristics | Effects on sensorial characteristics |
|---|---|---|---|---|
| **Beer (Gasiński et al., 2022)** | Pressed white grape pomace (Solaris)<br>10, 20% | ↓sugars<br>↑tartaric, malic, acetic, lactic acids<br>↑TPC<br>↑antioxidant capacity<br>↓acetaldehyde | ↑ethanol content<br>↓pH<br>↑EBC colour (darker) | - |
| **Coconut water (Costa et al., 2021)** | Microencapsulated grape pomace extract<br>2, 2.5% | ↑antimicrobial capacity<br>↑prebiotic potential | - | - no significant differences in texture, coconut aroma intensity, sweetness, saltiness<br>- significant differences - general appearance, aroma<br>- the major difference - colour |

TPC – total phenolic content, EBC - European Brewery Convention, ↑- increase, ↓- decrease

### 4.5.1 Effects on nutritional aspects

Gasiński et al., (2022) developed a process for incorporating white grape pomace (WGP) into the formulation of beer. WGP was immediately frozen after pressing and defrosted before use. Half of the WGP was subjected to a heat treatment at 70°C for 10 minutes before adding it to fermenters containing beer, while the other half was directly added to beer after defrosting. Four beer variations were created: U10 and U20 with 10% and 20% unpasteurised

WGP, and P10 and P20 with 10% and 20% heat-treated WGP respectively. Interestingly, the addition of WGP led to a decrease in certain sugars, such as dextrins and maltotriose. This can be attributed to the dilution of the beer due to the presence of significant water content in the pomace. This dilution effect leads to a reduction in the concentration of sugars. Moreover, the U10 and U20 samples exhibited lower dextrin concentrations compared to the P10 and P20 samples. This suggests that the addition of unpasteurised WGP introduced indigenous microbiota capable of fully utilising some of the dextrins that the yeast *Saccharomyces cerevisiae* cannot metabolise completely, leading to their decreased levels (Armijo et al., 2016; Gasiński et al., 2022).

The addition of white grape pomace to beer resulted in a significant increase in the concentration of certain organic acids (Gasiński et al., 2022). Tartaric acid, naturally abundant in grapes (dos Santos Lima et al., 2015), showed a notable increase in beers with WGP. Similarly, malic acid, though present in grapes at lower concentrations than tartaric acid, also increased with grape pomace addition. The increase in these organic acids can be attributed to the incorporation of pomace, which brings along the natural acids present in the grapes themselves (Gasiński et al., 2022).

Incorporating WGP into beer led to a notable decrease in acetaldehyde levels when compared to the control group (Gasiński et al., 2022). Acetaldehyde is a compound produced by yeast during ethanol fermentation. While low concentrations of acetaldehyde contribute to a pleasant aroma reminiscent of green apples, higher concentrations can negatively affect flavour, imparting an unpleasant etheric and pungent aroma (Gasiński et al., 2022; Liu et al., 2018). Additionally, high levels of acetaldehyde can inhibit cell growth and exert more significant toxicity and stress on humans and yeast compared to ethanol (Gasiński et al., 2022; Matsufuji et al., 2013).

The incorporation of grape pomace into beer led to an increase in total phenolic content (TPC) and enhanced antioxidant activity (Gasiński et al., 2022). The concentration of TPC in the tested beers increased with higher amounts of grape pomace added. For example, the beer with 20% WGP exhibited nearly 2.5 times the concentration of total phenolic compounds compared to the control. The antioxidant activity of the beers also increased significantly, with the highest antioxidant activity observed in the beer containing 20% pasteurised WGP (Gasiński et al., 2022).

Coconut beverages enriched with grape pomace extract demonstrated antimicrobial properties and growth-retarding effects against pathogens such as *Staphylococcus aureus*, *Candida albicans*, and *Listeria monocytogenes* (Costa et al., 2021). The functional coconut beverages, even with a GPE concentration of only 2.5% (weight/volume), showed the ability to inhibit or retard the growth of these microorganisms. The addition of microencapsulated GPE resulted in increased growth of the probiotic microorganisms, with the enriched beverage promoting higher growth in some strains compared to fructooligosaccharides (FOS), a commonly used prebiotic control (Costa et al., 2021).

### 4.5.2 Effects on technological characteristics

The effects of adding grape pomace extract on the technological characteristics of beer were investigated in the study conducted by Gasiński et al., (2022). The addition of WGP resulted in several notable changes in the beer's properties.

Firstly, the beers containing WGP exhibited higher ethanol concentrations compared to those without grape pomace. This increase in ethanol concentration can be attributed to the addition of fermentable sugars present in WGP, which provide additional substrates for yeast fermentation.

Secondly, the pH value of the beers decreased when WGP was added. This reduction in pH corresponds to an increase in organic acid concentration in all samples with WGP. The presence of organic acids in the beer can contribute to its flavour profile and acidity.

Additionally, the addition of WGP led to an increase in the EBC colour parameter of the beer. EBC stands for the European Brewery Convention, and it is a standard measurement system used to assess the colour of beer (Koren et al., 2020). The increase in EBC indicates a darker colour of the beer. This change in colour is likely due to the browning reactions that occur between the polyphenols present in WGP and other components in the beer during the brewing process (Gasiński et al., 2022).

### 4.5.3 Effects on sensorial characteristics

Costa et al., (2021) investigated the impact of incorporating grape pomace on the sensory properties of coconut water. The study compared a control group of coconut water with two systems of microencapsulation of the grape pomace extract: one with alginate (GPE-Alg), and another with chitosan (GPE-CS). The results showed no significant differences in texture, coconut aroma intensity, sweetness, and saltiness between the control group and the GPE-Alg or GPE-CS variations. However, significant differences were observed in general appearance, aroma, and flavour. The flavour of the beverages with GPE-Alg and GPE-CS was significantly different, GPE-CS showing a slightly bitter flavour, likely due to the inability of chitosan to mask the bitterness of some phytochemicals in the GPE. The most significant difference was observed in the colour of the beverage, with the GPE variations providing a pinkish colour due to the anthocyanins present in the grape pomace extract.

# V. Challenges and limitations

The utilisation of grape pomace in functional food production undoubtedly presents various advantages. However, it is crucial to acknowledge and address the accompanying challenges and limitations. One such challenge is the high variability in the composition of grape pomace, which can impact the consistency and quality of the end products. Additionally, consumer acceptance of enriched products can be a limitation, as some individuals may be hesitant to embrace foods fortified with grape pomace due to unfamiliarity or perceived changes in taste and texture. Ensuring the stability of the fortified products over time is another consideration, as the phenolic compounds present in grape pomace can be susceptible to degradation or loss of bioactivity. Lastly, the processing of grape pomace into flours or extracting phenolics can present technical challenges, including the selection of appropriate extraction methods and optimization of processing parameters to minimise the energy input.

## 5.1 Variability in composition

Numerous factors such as grape variety, ripening stage, winemaking procedures, climate, soil conditions, and processing methods influence the chemical composition of grape pomace (Abdelhakam et al., 2019; Barriga-Sánchez et al., 2022; Ilyas et al., 2021; Iuga and Mironeasa, 2020; Nakov et al., 2020). This variability may impact the consistency of bioactive compounds and sensory characteristics in functional food formulations. Thus, achieving consistent quality and desired properties in functional food products made from grape pomace becomes a challenge for manufacturers. To overcome this issue, it is important for manufacturers to carefully consider the sources of grape pomace and implement strategies to address the inherent variability. Manufacturers are advised to continually adjust their recipes, considering the output of simulation and analysis tools that consider the variability of available ingredients (Riddick et al., 2016). The concept of Smart Manufacturing can be applied to navigate the complexities associated with grape pomace variability and regulatory compliance, ultimately delivering high-quality functional food products to consumers (Riddick et al., 2016).

## 5.2 Sensory acceptance

Functional food products made with the addition of grape pomace may have a different taste or texture than traditional food products, which can make them less appealing to consumers. For example, the presence of catechin, epicatechin, and proanthocyanidins in grape seeds has been linked to a decrease in pleasant mouth sensations, resulting in an astringent effect in muffins and breadsticks (Bianchi et al., 2022; Troilo et al., 2022; Rainero et al., 2022). Dairy products like yoghurt generally received high overall liking scores (Fernández-Fernández et al., 2022; Iriondo-DeHond et al., 2020), but other products, like cheese, showed changes in texture and flavour, including astringency and acidity, which could negatively affect acceptance (Gaglio et al., 2021; Lucera et al., 2018). Similarly, meat and fish products experienced a decrease in acceptability once the grape pomace extract was added to the recipe (Cilli et al., 2020; Pereira et al., 2022). According to Boff et al., (2022), the degree of acceptance for high quantities of grape pomace in fortified products remains low. They also found that sensory acceptance improved when lower percentages of grape pomace flour, with or without seeds, were used (Boff et al., 2022). To address these challenges, it is crucial to determine the optimal amount and particle size of grape pomace to achieve good technological, physical, textural, and sensorial characteristics (Iuga and Mironeasa, 2020).

## 5.3 Stability of bioactive compounds

Wineries generate large quantities of waste within a limited period. As a result, the timely and efficient treatment of grape pomace becomes necessary shortly after wine production (Hogervorst et al., 2017). Maintaining the stability and extending the shelf life of functional food products fortified with grape pomace can be a challenge, as it contains bioactive compounds that can be sensitive to factors like oxidation, light, temperature, and moisture (Silva et al., 2022). Fresh grape pomace has a high moisture content (75-80%), which necessitates drying for long-term storage (Gerardi et al., 2020). The selection of drying method employed is crucial, as high temperatures can compromise the bioactivity of thermally sensitive compounds (Antony and Farid, 2022). Furthermore, choosing appropriate packaging materials and storage conditions should be considered to preserve the bioactivity and quality of the incorporated compounds (Silva et al., 2022).

## 5.4 Extraction challenges

While conventional extraction techniques like Soxhlet extraction, maceration, and solid-liquid extraction are widely accessible and offer satisfactory recovery, they are not without limitations (Hogervorst et al., 2017). Conventional extraction methods often involve heating the matrix, which can lead to the degradation or loss of bioactive compounds, thereby compromising their bioactivity and stability (Antony and Farid, 2022). Additionally, these methods tend to require high energy consumption and can be costly, which may present challenges in large-scale applications (Chakka and Babu, 2022). Furthermore, the use of organic solvents in conventional techniques may raise concerns regarding the safety and environmental impact of the extracted products (Hogervorst et al., 2017).

To overcome these limitations, green technologies have emerged as promising alternatives (Spigno et al., 2017). These include technologies such as ultrasound-assisted extraction, microwave-assisted extraction, supercritical fluid extraction, and enzyme-assisted extraction (Ilyas et al., 2021). These green extraction technologies not only offer improved extraction efficiency but also address concerns related to energy consumption, solvent usage, and the stability of the extracted compounds (Maroun et al., 2017). By adopting these modern techniques, researchers and manufacturers can achieve higher yields, better preservation of bioactivity, and reduced environmental impact in the extraction of bioactive compounds from grape pomace.

## 5.5 Processing challenges

Drying and milling grape pomace into powder offers a convenient form for incorporation into various food application, however it is important to note that this approach also has several disadvantages. Firstly, the high moisture content of fruit pomace poses a challenge for drying processes. Currently, energy-intensive technologies like forced air drying are commonly employed to reduce the moisture content (Iqbal et al., 2021), however, these methods can contribute to environmental concerns due to their high energy consumption. The processing of grape pomace may result in the loss of certain bioactive compounds, such as volatile aromas and delicate phytochemicals, which can be sensitive to mechanical forces and heat generated during drying and milling (Antony and Farid, 2022). Additionally, the particle size of the milled grape pomace flour needs to be carefully controlled to ensure uniformity and desired functional properties in the final product. In some cases, achieving the desired particle size distribution can be challenging, potentially affecting the texture, palatability, and overall quality of the fortified food product (Altınok et al., 2022). To overcome these drawbacks, alternative processing techniques can be explored. The Spiral Flash drying technology has shown promise for dehydrating grape pomace at an industrial scale while retaining heat-sensitive anthocyanins and non-coloured phenolic compounds (Souza da Costa et al., 2022). The Spiral Flash technology combines the advantages of flash drying and fluidised bed drying, offering potential for efficient drying of grape pomace while preserving its bioactive components (Souza da Costa et al., 2022).

# VI. Conclusions and future research

Grape pomace emerges as a valuable source of nutrients and bioactive compounds. Notably, dietary fibre and polyphenols stand out as the primary bioactive compounds present, making grape pomace suitable for fortification purposes. The recycling of winery by-products presents an opportunity to reduce costs, minimize environmental impact, and promote human health. The bioactive compounds found in grape pomace have been linked to a range of beneficial properties, including antioxidant, antimicrobial, anti-inflammatory, and anticancer effects. Integration of grape pomace into various food products has yielded positive outcomes, such as increased polyphenolic content and improved oxidative stability. However, it is crucial to consider that high fortification levels may impact sensorial and textural characteristics. Nevertheless, the potential for grape pomace valorisation remains significant, particularly in the bakery sector, where it can enhance the nutritional value of products like muffins and biscuits without compromising technological and sensory quality. Optimization of fortification levels becomes crucial in meat and fish products, as well as specific dairy products, like cheese, to achieve desired outcomes.

By highlighting successful product formulations and encouraging their adoption, this review seeks to bridge the gap between scientific knowledge and practical implementation. This not only promotes sustainable practices, but also fosters new collaborations within the industry. Through the implementation of innovative approaches, wineries can significantly reduce their environmental footprint and contribute to a resource-efficient economy. The insights from this review can also support efforts aimed at driving legislative changes that recognize and support the alternative uses of grape pomace on a larger scale. Ultimately, the goal is to create a more sustainable and environmentally conscious winemaking industry, where the value of by-products like grape pomace is fully recognised and harnessed for the benefit of both the industry, the society, and the environment.

Future research in the field of grape pomace valorisation should focus on various aspects to advance its utilisation in functional food products. Firstly, determining the bioavailability of the compounds present in products enriched with grape pomace is essential to understand their potential health benefits and ensure effective absorption by the human body. Additionally, efforts should be made to improve the sensorial quality of these products, addressing any undesirable taste, texture, colour, or overall acceptability issues that may arise. Finding innovative methods to maintain the stability and extend the shelf life of grape pomace powder, considering its large-scale production within a short timeframe, is crucial to preserve its bioactive compounds and prevent degradation. Furthermore, exploring modern extraction and drying technologies that preserve the bioactive compounds without excessive energy consumption or environmental impact is necessary. Finally, conducting life cycle assessments of products enriched with grape by-products would provide valuable insights into their overall environmental footprint and guide sustainable decision-making. By addressing these considerations, future research can contribute to maximising the potential of grape pomace as a valuable ingredient in functional foods, ensuring enhanced bioavailability, sensory quality, stability, and environmental sustainability.

# References:

Abdelhakam, O., Elsebaie, E., Ghazi, A., Gouda, M., 2019. QUALITY CHARACTERISTICS OF BEEF HAMBURGER ENRICHED WITH RED GRAPE POMACE POWDER DURING FREEZING STORAGE. Slov. Vet. Res. 56. https://doi.org/10.26873/SVR-772-2019

Altinok, E., Kurultay, S., Boluk, E., Atik, D.S., Kopuk, B., Gunes, R., Palabiyik, I., Konar, N., Toker, O.S., 2022. Investigation of using possibility of grape pomace in wafer sheet for wheat flour substitution. Int. J. Food Sci. Technol. 57, 3634–3642. https://doi.org/10.1111/ijfs.15687

Altınok, E., Kurultay, S., Konar, N., Toker, O.S., Kopuk, B., Gunes, R., Palabiyik, I., 2022. Utilising grape juice processing by-products as bulking and colouring agent in white chocolate. Int. J. Food Sci. Technol. 57, 4119–4128. https://doi.org/10.1111/ijfs.15728

Amaya-Chantaca, D., Flores-Gallegos, A.C., Iliná, A., Aguilar, C.N., Verma, D.K., Baranwal, D., Chávez-González, M.L., 2022. Wine waste as a potential source of bioactive compounds, in: Innovations in Fermentation and Phytopharmaceutical Technologies. Elsevier, pp. 361–380. https://doi.org/10.1016/B978-0-12-821877-8.00003-8

Antonić, B., Jančíková, S., Dordević, D., Tremlová, B., 2020. Grape pomace valorization: A systematic review and meta-analysis. Foods 9. https://doi.org/10.3390/foods9111627

Antony, A., Farid, M., 2022. Effect of Temperatures on Polyphenols during Extraction. Appl. Sci. 12, 2107. https://doi.org/10.3390/app12042107

Armijo, G., Schlechter, R., Agurto, M., Muñoz, D., Nuñez, C., Arce-Johnson, P., 2016. Grapevine pathogenic microorganisms: Understanding infection strategies and host response scenarios. Front. Plant Sci. 7. https://doi.org/10.3389/fpls.2016.00382

Arvanitoyannis, I.S., Ladas, D., Mavromatis, A., 2006. Potential uses and applications of treated wine waste: a review. Int. J. Food Sci. Technol. 41, 475–487. https://doi.org/10.1111/j.1365-2621.2005.01111.x

Balasundram, N., Sundram, K., Samman, S., 2006. Phenolic compounds in plants and agri-industrial by-products: Antioxidant activity, occurrence, and potential uses. Food Chem. 99, 191–203. https://doi.org/10.1016/j.foodchem.2005.07.042

Baldán, Y., Riveros, M., Fabani, M.P., Rodriguez, R., 2021. Grape pomace powder valorization: a novel ingredient to improve the nutritional quality of gluten-free muffins. Biomass Convers. Biorefinery. https://doi.org/10.1007/s13399-021-01829-8

Barriga-Sánchez, M., Hiparraguirre, H.C., Rosales-Hartshorn, M., 2022. Chemical composition and mineral content of Black Borgoña (Vitis labrusca L.) grapes, pomace and seeds, and effects of conventional and non-conventional extraction methods on their antioxidant properties. Food Sci. Technol. 42, e120021. https://doi.org/10.1590/fst.120021

Bello, L., 2020. Fecce e vinacce, lo smaltimento | SportelloAgricoltura.it | Professionisti in agricoltura [WWW Document]. URL https://sportelloagricoltura.it/circolari-mondo-agricolo/fecce-e-vinacce-lo-smaltimento/ (accessed 7.2.23).

Bento da Silva, A., Koistinen, V., Mena, P., Bronze, M., Hanhineva, K., Sahlstrøm, S., Kitryte, V., Moco, S., Aura, A.-M., 2020. Factors affecting intake, metabolism and health benefits of phenolic acids: do we understand individual variability? Eur. J. Nutr. 59. https://doi.org/10.1007/s00394-019-01987-6

Beres, C., Costa, G.N.S., Cabezudo, I., da Silva-James, N.K., Teles, A.S.C., Cruz, A.P.G., Mellinger-Silva, C., Tonon, R.V., Cabral, L.M.C., Freitas, S.P., 2017. Towards integral utilization of grape pomace from winemaking process: A review. Waste Manag. 68, 581–594. https://doi.org/10.1016/j.wasman.2017.07.017

Beres, C., Freitas, S.P., Godoy, R.L. de O., de Oliveira, D.C.R., Deliza, R., Iacomini, M., Mellinger-Silva, C., Cabral, L.M.C., 2019. Antioxidant dietary fibre from grape pomace flour or extract: Does it make any difference on the nutritional and functional value? J. Funct. Foods 56, 276–285. https://doi.org/10.1016/j.jff.2019.03.014

Bianchi, F., Cervini, M., Giuberti, G., Rocchetti, G., Lucini, L., Simonato, B., 2022. Distilled grape pomace as a functional ingredient in vegan muffins: effect on physicochemical, nutritional, rheological and sensory aspects. Int. J. Food Sci. Technol. 57, 4847–4858. https://doi.org/10.1111/ijfs.15720

Boff, J.M., Strasburg, V.J., Ferrari, G.T., de Oliveira Schmidt, H., Manfroi, V., de Oliveira, V.R., 2022. Chemical, Technological, and Sensory Quality of Pasta and Bakery Products Made with the Addition of Grape Pomace Flour. Foods 11. https://doi.org/10.3390/foods11233812

Bordiga, M., Travaglia, F., Locatelli, M., Arlorio, M., Coïsson, J.D., 2015. Spent grape pomace as a still potential by-product. Int. J. Food Sci. Technol. 50, 2022–2031. https://doi.org/10.1111/ijfs.12853

Bursa, K., Kilicli, M., Toker, O.S., Palabiyik, I., Gulcu, M., Yaman, M., Kian-Pour, N., Konar, N., 2022. Formulating and studying compound chocolate with adding dried grape pomace as a bulking agent. J. Food Sci. Technol. 59, 1704–1714. https://doi.org/10.1007/s13197-021-05180-8

California Assembly Bill AB-1826 Solid waste: organic waste. [WWW Document], n.d. URL https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB1826&search_keywords (accessed 6.26.23).

Campos, F., Peixoto, A.F., Fernandes, P.A.R., Coimbra, M.A., Mateus, N., de Freitas, V., Fernandes, I., Fernandes, A., 2021. The Antidiabetic Effect of Grape Pomace Polysaccharide-Polyphenol Complexes. Nutrients 13, 4495. https://doi.org/10.3390/nu13124495

Canalejo, D., Guadalupe, Z., Martínez-Lapuente, L., Ayestarán, B., Pérez-Magariño, S., Doco, T., 2022. Characterization of polysaccharide extracts recovered from different grape and winemaking products. Food Res. Int. 157, 111480. https://doi.org/10.1016/j.foodres.2022.111480

Carmona-Jiménez, Y., Igartuburu, J.M., Guillén-Sánchez, D.A., García-Moreno, M.V., 2022. Fatty Acid and Tocopherol Composition of Pomace and Seed Oil from Five Grape Varieties Southern Spain. Molecules 27, 6980. https://doi.org/10.3390/molecules27206980

Carpes, S.T., Pereira, D., Moura, C. de, Reis, A.S. dos, Silva, L.D. da, Oldoni, T.L.C., Almeida, J.F., Plata-Oviedo, M.V.S., 2020. Lyophilized and microencapsulated extracts of grape pomace from winemaking industry to prevent lipid oxidation in chicken pâté. Braz. J. Food Technol. 23, e2019112. https://doi.org/10.1590/1981-6723.11219

Carullo, G., Spizzirri, U.G., Montopoli, M., Cocetta, V., Armentano, B., Tinazzi, M., Sciubba, F., Giorgi, G., Enrica Di Cocco, M., Bohn, T., Aiello, F., Restuccia, D., 2022. Milk kefir enriched with inulin-grafted seed extract from white wine pomace: chemical characterisation, antioxidant profile and *in vitro* gastrointestinal digestion. Int. J. Food Sci. Technol. 57, 4086–4095. https://doi.org/10.1111/ijfs.15724

Castellanos-Gallo, L., Ballinas-Casarrubias, L., Espinoza-Hicks, J.C., Hernández-Ochoa, L.R., Muñoz-Castellanos, L.N., Zermeño-Ortega, M.R., Borrego-Loya, A., Salas, E., 2022. Grape Pomace Valorization by Extraction of Phenolic Polymeric Pigments: A Review. Processes 10, 469. https://doi.org/10.3390/pr10030469

Chakka, A.K., Babu, A.S., 2022. Bioactive Compounds of Winery by-products: Extraction Techniques and their Potential Health Benefits. Appl. Food Res. 2, 100058. https://doi.org/10.1016/j.afres.2022.100058

Chowdhary, P., Gupta, A., Gnansounou, E., Pandey, A., Chaturvedi, P., 2021. Current trends and possibilities for exploitation of Grape pomace as a potential source for value addition. Environ. Pollut. 278. https://doi.org/10.1016/j.envpol.2021.116796

Cilli, L.P., Contini, L.R.F., Sinnecker, P., Lopes, P.S., Andreo, M.A., Neiva, C.R.P., Nascimento, M.S., Yoshida, C.M.P., Venturini, A.C., 2020. Effects of grape pomace flour on quality parameters of salmon burger. J. Food Process. Preserv. 44. https://doi.org/10.1111/jfpp.14329

Cisneros-Yupanqui, M., Rizzi, C., Mihaylova, D., Lante, A., 2022. Effect of the distillation process on polyphenols content of grape pomace. Eur. Food Res. Technol. 248, 929–935. https://doi.org/10.1007/s00217-021-03924-6

Coelho, M.C., Ghalamara, S., Pereira, R., Rodrigues, A.S., Teixeira, J.A., Pintado, M.E., 2023. Innovation and Winemaking By-Product Valorization: An Ohmic Heating Approach. Processes 11, 495. https://doi.org/10.3390/pr11020495

Cooper, K., Chopra, M., Thurnham, D., 2004. Wine polyphenols and promotion of cardiac health. Nutr. Res. Rev. 17, 111–30. https://doi.org/10.1079/NRR200482

Costa, J.R., Monteiro, M.J., Tonon, R.V., Cabral, L.M.C., Pastrana, L., Pintado, M.E., 2021. Fortification of coconut water with microencapsulated grape pomace extract towards a novel electrolyte beverage: Biological, sensorial and quality aspects. Future Foods 4, 100079. https://doi.org/10.1016/j.fufo.2021.100079

De Graef, V., Depypere, F., Minnaert, M., Dewettinck, K., 2011. Chocolate yield stress as measured by oscillatory rheology. Food Res. Int. 44, 2660–2665. https://doi.org/10.1016/j.foodres.2011.05.009

Difonzo, G., Troilo, M., Allegretta, I., Pasqualone, A., Caponio, F., 2023. Grape skin and seed flours as functional ingredients of pizza: Potential and drawbacks related to nutritional, physicochemical and sensory attributes. LWT 175, 114494. https://doi.org/10.1016/j.lwt.2023.114494

dos Santos Lima, M., da Conceição Prudêncio Dutra, M., Toaldo, I.M., Corrêa, L.C., Pereira, G.E., de Oliveira, D., Bordignon-Luiz, M.T., Ninow, J.L., 2015. Phenolic compounds, organic acids and antioxidant activity of grape juices produced in industrial scale by different processes of maceration. Food Chem. 188, 384–392. https://doi.org/10.1016/j.foodchem.2015.04.014

dos Santos Silva, M.E., de Oliveira, R.L., Sousa, T.C. de A., Grisi, C.V.B., Ferreira, V.C. da S., Porto, T.S., Madruga, M.S., Silva, S.P. da, Silva, F.A.P. da, 2022. Microencapsulated phenolic-rich extract from juice processing grape pomace (Vitis labrusca. Isabella Var): Effects on oxidative stability of raw and pre-cooked bovine burger. Food Biosci. 50, 102212. https://doi.org/10.1016/j.fbio.2022.102212

Dwyer, K., Hosseinian, F., Rod, M., 2014. The Market Potential of Grape Waste Alternatives. J. Food Res. 3, 91. https://doi.org/10.5539/jfr.v3n2p91

El Bouchikhi, S., Pagès, P., El Alaoui, Y., Ibrahimi, A., Bensouda, Y., 2019. Syneresis investigations of lacto-fermented sodium caseinate in a mixed model system. BMC Biotechnol. 19, 57. https://doi.org/10.1186/s12896-019-0539-1

European Commission, 2021. Dietary recommendations for dietary fibre intake [WWW Document]. URL https://knowledge4policy.ec.europa.eu/health-promotion-knowledge-gateway/dietary-fibre-recommendations-2_en (accessed 5.19.23).

FAO, 2022. Agricultural production statistics 2000–2021. FAOSTAT Anal. Brief Ser. No 60 Rome. https://doi.org/10.4060/cc3751en

FDA, 2021. Questions and Answers on Dietary Fiber [WWW Document]. FDA. URL https://www.fda.gov/food/food-labeling-nutrition/questions-and-answers-dietary-fiber (accessed 6.15.23).

Fernández-Fernández, A.M., Dellacassa, E., Nardin, T., Larcher, R., Ibañez, C., Terán, D., Gámbaro, A., Medrano-Fernandez, A., del Castillo, M.D., 2022. Tannat Grape Skin: A Feasible Ingredient for the Formulation of Snacks with Potential for Reducing the Risk of Diabetes. Nutrients 14, 419. https://doi.org/10.3390/nu14030419

Fontana, A.R., Antoniolli, A., Bottini, R., 2013. Grape Pomace as a Sustainable Source of Bioactive Compounds: Extraction, Characterization, and Biotechnological Applications of Phenolics. J. Agric. Food Chem. 61, 8987–9003. https://doi.org/10.1021/jf402586f

Fontana, M., Murowaniecki Otero, D., Pereira, A.M., Santos, R.B., Gularte, M.A., 2022. Grape Pomace Flour for Incorporation into Cookies: Evaluation of Nutritional, Sensory and Technological Characteristics. J. Culin. Sci. Technol. 1–20. https://doi.org/10.1080/15428052.2022.2086956

Gaglio, R., Restivo, I., Barbera, M., Barbaccia, P., Ponte, M., Tesoriere, L., Bonanno, A., Attanzio, A., Di Grigoli, A., Francesca, N., Moschetti, G., Settanni, L., 2021. Effect on the Antioxidant, Lipoperoxyl Radical Scavenger Capacity, Nutritional, Sensory and Microbiological Traits of an Ovine Stretched Cheese Produced with Grape Pomace Powder Addition. Antioxidants 10, 306. https://doi.org/10.3390/antiox10020306

García-Lomillo, J., González-SanJosé, M.L., 2017. Applications of Wine Pomace in the Food Industry: Approaches and Functions. Compr. Rev. Food Sci. Food Saf. 16, 3–22. https://doi.org/10.1111/1541-4337.12238

Gasiński, A., Kawa-Rygielska, J., Mikulski, D., Kłosowski, G., Głowacki, A., 2022. Application of white grape pomace in the brewing technology and its impact on the concentration of esters and alcohols, physicochemical parameteres and antioxidative properties of the beer. Food Chem. 367, 130646. https://doi.org/10.1016/j.foodchem.2021.130646

Gerardi, C., D'amico, L., Migoni, D., Santino, A., Salomone, A., Carluccio, M.A., Giovinazzo, G., 2020. Strategies for Reuse of Skins Separated From Grape Pomace as Ingredient of Functional Beverages. Front. Bioeng. Biotechnol. 8. https://doi.org/10.3389/fbioe.2020.00645

Gitea, M.A., Bungau, S.G., Gitea, D., Pasca, B.M., Purza, A.L., Radu, A.-F., 2023. Evaluation of the Phytochemistry–Therapeutic Activity Relationship for Grape Seeds Oil. Life 13, 178. https://doi.org/10.3390/life13010178

Haque, A., Ahmad, S., Azad, Z.R.A.A., Adnan, M., Ashraf, S.A., 2023. Incorporating dietary fiber from fruit and vegetable waste in meat products: a systematic approach for sustainable meat processing and improving the functional, nutritional and health attributes. PeerJ 11, e14977. https://doi.org/10.7717/peerj.14977

Herderich, M.J., Smith, P.A., 2005. Analysis of grape and wine tannins: Methods, applications and challenges. Aust. J. Grape Wine Res. 11, 205–214. https://doi.org/10.1111/j.1755-0238.2005.tb00288.x

Hogervorst, J.C., Miljić, U., Puškaš, V., 2017. Extraction of Bioactive Compounds from Grape Processing By-Products, in: Handbook of Grape Processing By-Products: Sustainable Solutions. Elsevier Inc., pp. 105–135. https://doi.org/10.1016/B978-0-12-809870-7.00005-3

Ilyas, T., Chowdhary, P., Chaurasia, D., Gnansounou, E., Pandey, A., Chaturvedi, P., 2021. Sustainable green processing of grape pomace for the production of value-added products: An overview. Environ. Technol. Innov. 23, 101592. https://doi.org/10.1016/j.eti.2021.101592

Iqbal, A., Schulz, P., Rizvi, S.S.H., 2021. Valorization of bioactive compounds in fruit pomace from agro-fruit industries: Present Insights and future challenges. Food Biosci. 44, 101384. https://doi.org/10.1016/j.fbio.2021.101384

Iriondo-DeHond, M., Blázquez-Duff, J.M., del Castillo, M.D., Miguel, E., 2020. Nutritional Quality, Sensory Analysis and Shelf Life Stability of Yogurts Containing Inulin-Type Fructans and Winery Byproducts for Sustainable Health. Foods 9, 1199. https://doi.org/10.3390/foods9091199

Iuga, M., Mironeasa, S., 2020. Potential of grape byproducts as functional ingredients in baked goods and pasta. Compr. Rev. Food Sci. Food Saf. 19, 2473–2505. https://doi.org/10.1111/1541-4337.12597

Kalli, E., Lappa, I., Bouchagier, P., Tarantilis, P.A., Skotti, E., 2018. Novel application and industrial exploitation of winery by-products. Bioresour. Bioprocess. 5. https://doi.org/10.1186/s40643-018-0232-6

Koren, D., Hegyesné Vecseri, B., Kun-Farkas, G., Urbin, Á., Nyitrai, Á., Sipos, L., 2020. How to objectively determine the color of beer? J. Food Sci. Technol. 57, 1183–1189. https://doi.org/10.1007/s13197-020-04237-4

Lempereur, V., Penavayre, S., 2014. Grape marc, wine lees and deposit of the must: How to manage oenological by-products? BIO Web Conf. 3, 01011. https://doi.org/10.1051/bioconf/20140301011

Liu, C., Li, Q., Niu, C., Tian, Y., Zhao, Y., Yin, X., 2018. The use of atmospheric and room temperature plasma mutagenesis to create a brewing yeast with reduced acetaldehyde production. J. Inst. Brew. 124, 236–243. https://doi.org/10.1002/jib.498

Lou, W., Zhou, H., Li, B., Nataliya, G., 2022. Rheological, pasting and sensory properties of biscuits supplemented with grape pomace powder. Food Sci. Technol. 42, e78421. https://doi.org/10.1590/fst.78421

Lucera, A., Costa, C., Marinelli, V., Saccotelli, M., Del Nobile, M., Conte, A., 2018. Fruit and Vegetable By-Products to Fortify Spreadable Cheese. Antioxidants 7, 61. https://doi.org/10.3390/antiox7050061

Malaguti, M., Angeloni, C., Hrelia, S., 2013. Polyphenols in Exercise Performance and Prevention of Exercise-Induced Muscle Damage. Oxid. Med. Cell. Longev. 2013, 825928. https://doi.org/10.1155/2013/825928

Maroun, R.G., Rajha, H.N., Vorobiev, E., Louka, N., 2017. Emerging Technologies for the Recovery of Valuable Compounds From Grape Processing By-Products, in: Handbook of Grape Processing By-Products: Sustainable Solutions. Elsevier Inc., pp. 155–181. https://doi.org/10.1016/B978-0-12-809870-7.00007-7

Matsufuji, Y., Yamamoto, K., Yamauchi, K., Mitsunaga, T., Hayakawa, T., Nakagawa, T., 2013. Novel physiological roles for glutathione in sequestering acetaldehyde to confer acetaldehyde tolerance in Saccharomyces cerevisiae. Appl. Microbiol. Biotechnol. 97, 297–303. https://doi.org/10.1007/s00253-012-4147-4

Moate, P.J., Jacobs, J.L., Hixson, J.L., Deighton, M.H., Hannah, M.C., Morris, G.L., Ribaux, B.E., Wales, W.J., Williams, S.R.O., 2020. Effects of Feeding either Red or White Grape Marc on Milk Production and Methane Emissions from Early-Lactation Dairy Cows. Animals 10, 976. https://doi.org/10.3390/ani10060976

Moate, P.J., Williams, S.R.O., Torok, V.A., Hannah, M.C., Ribaux, B.E., Tavendale, M.H., Eckard, R.J., Jacobs, J.L., Auldist, M.J., Wales, W.J., 2014. Grape marc reduces methane emissions when fed to dairy cows. J. Dairy Sci. 97, 5073–5087. https://doi.org/10.3168/jds.2013-7588

Mohamed Ahmed, I.A., Özcan, M.M., Al Juhaimi, F., Babiker, E.F.E., Ghafoor, K., Banjanin, T., Osman, M.A., Gassem, M.A., Alqah, H.A.S., 2020. Chemical composition, bioactive compounds, mineral contents, and fatty acid composition of pomace powder of different grape varieties. J. Food Process. Preserv. 44. https://doi.org/10.1111/jfpp.14539

Mohsen, S.M., Fadel, H.H.M., Bekhit, M.A., Edris, A.E., Ahmed, M.Y.S., 2009. Effect of substitution of soy protein isolate on aroma volatiles, chemical composition and sensory quality of wheat cookies. Int. J. Food Sci. Technol. 44, 1705–1712. https://doi.org/10.1111/j.1365-2621.2009.01978.x

Nakov, G., Brandolini, A., Hidalgo, A., Ivanova, N., Stamatovska, V., Dimov, I., 2020. Effect of grape pomace powder addition on chemical, nutritional and technological properties of cakes. LWT 134, 109950. https://doi.org/10.1016/j.lwt.2020.109950

Nistor, E., Dobrei, A., Bampidis, V., Ciolac, V., 2014. Grape pomace in sheep and dairy cows feeding. J. Hortic. For. Biotechnol. 18(2), 146–150.

OIV, 2021. Annual Assessment of the World Vine and Wine Sector in 2021. https://www.oiv.int/sites/default/files/documents/OIV_Annual_Assessment_of_the_World_Vine_and_Wine_Sector_in_2021.pdf

Oliveira, B.E., Contini, L., Garcia, V.A. dos S., Cilli, L.P. de L., Chagas, E.G.L., Andreo, M.A., Vanin, F.M., Carvalho, R.A., Sinnecker, P., Venturini, A.C., Yoshida, C.M.P., 2022. Valorization of grape by-products as functional and nutritional ingredients for healthy pasta development. J. Food Process. Preserv. 46. https://doi.org/10.1111/jfpp.17245

Olt, V., Baéz, J., Jorcin, S., López, T., Fernández-Fernández, A.M., Medrano Fernandez, A., 2022. Encapsulated bioactive compounds from a winemaking byproduct for its application as functional ingredient in yogurt. Agrociencia Urug. 25. https://doi.org/10.31285/agro.25.794

Pereira, A., Lee, H.C., Lammert, R., Wolberg, C., Ma, D., Immoos, C., Casassa, F., Kang, I., 2022. Effects of red-wine grape pomace on the quality and sensory attributes of beef hamburger patty. Int. J. Food Sci. Technol. 57, 1814–1823. https://doi.org/10.1111/ijfs.15559

Quaglio, A.E.V., Grillo, T.G., Oliveira, E.C.S.D., Stasi, L.C.D., Sassaki, L.Y., 2022. Gut microbiota, inflammatory bowel disease and colorectal cancer. World J. Gastroenterol. 28, 4053–4060. https://doi.org/10.3748/wjg.v28.i30.4053

Rainero, G., Bianchi, F., Rizzi, C., Cervini, M., Giuberti, G., Simonato, B., 2022. Breadstick fortification with red grape pomace: effect on nutritional, technological and sensory properties. J. Sci. Food Agric. 102, 2545–2552. https://doi.org/10.1002/jsfa.11596

Raphael, W., Sordillo, L., 2013. Dietary Polyunsaturated Fatty Acids and Inflammation: The Role of Phospholipid Biosynthesis. Int. J. Mol. Sci. 14, 21167–21188. https://doi.org/10.3390/ijms141021167

Riddick, F., Wallace, E., Davis, J., 2016. Managing Risks Due to Ingredient Variability in Food Production. J. Res. Natl. Inst. Stand. Technol. 121, 17. https://doi.org/10.6028/jres.121.002

Siebert, K.J., Troukhanova, N.V., Lynn, P.Y., 1996. Nature of Polyphenol−Protein Interactions. J. Agric. Food Chem. 44, 80–85. https://doi.org/10.1021/jf9502459

Silva, A., Silva, V., Igrejas, G., Aires, A., Falco, V., Valentão, P., Poeta, P., 2023. Phenolic compounds classification and their distribution in winemaking by-products. Eur. Food Res. Technol. 249, 207–239. https://doi.org/10.1007/s00217-022-04163-z

Silva, M.E. dos S., Grisi, C.V.B., Silva, S.P. da, Madruga, M.S., Silva, F.A.P. da, 2022. The technological potential of agro-industrial residue from grape pulping (Vitis spp.) for application in meat products: A review. Food Biosci. 49, 101877. https://doi.org/10.1016/j.fbio.2022.101877

Silva, V.O., Freitas, A.A., Maçanita, A.L., Quina, F.H., 2016. Chemistry and photochemistry of natural plant pigments: the anthocyanins. J. Phys. Org. Chem. 29, 594–599. https://doi.org/10.1002/poc.3534

Sirohi, R., Tarafdar, A., Singh, S., Negi, T., Gaur, V.K., Gnansounou, E., Bharathiraja, B., 2020. Green processing and biotechnological potential of grape pomace: Current trends and opportunities for sustainable biorefinery. Bioresour. Technol. 314, 123771. https://doi.org/10.1016/j.biortech.2020.123771

Sousa, E.C., Uchôa-Thomaz, A.M.A., Carioca, J.O.B., Morais, S.M. de, Lima, A. de, Martins, C.G., Alexandrino, C.D., Ferreira, P.A.T., Rodrigues, A.L.M., Rodrigues, S.P., Silva, J. do N., Rodrigues, L.L., 2014. Chemical composition and bioactive compounds of grape pomace (Vitis vinifera L.), Benitaka variety, grown in the semiarid region of Northeast Brazil. Food Sci. Technol. Camp. 34, 135–142. https://doi.org/10.1590/S0101-20612014000100020

Souza da Costa, B., Soldevilla Muro, G., Oliván García, M., Motilva, M.J., 2022. Winemaking by-products as a source of phenolic compounds: Comparative study of dehydration processes. LWT 165. https://doi.org/10.1016/j.lwt.2022.113774

Spigno, G., Marinoni, L., Garrido, G.D., 2017. State of the Art in Grape Processing By-Products, in: Handbook of Grape Processing By-Products: Sustainable Solutions. Elsevier Inc., pp. 1–27. https://doi.org/10.1016/B978-0-12-809870-7.00001-6

Spinei, M., Oroian, M., 2021. The Potential of Grape Pomace Varieties as a Dietary Source of Pectic Substances. https://doi.org/10.3390/foods

Teixeira, A., Baenas, N., Dominguez-Perles, R., Barros, A., Rosa, E., Moreno, D.A., Garcia-Viguera, C., 2014. Natural bioactive compounds from winery by-products as health promoters: A review. Int. J. Mol. Sci. 15, 15638–15678. https://doi.org/10.3390/ijms150915638

Tikhonova, A., Ageeva, N., Globa, E., 2021. Grape pomace as a promising source of biologically valuable components. BIO Web Conf. 34, 06002. https://doi.org/10.1051/bioconf/20213406002

Tolve, R., Pasini, G., Vignale, F., Favati, F., Simonato, B., 2020. Effect of Grape Pomace Addition on the Technological, Sensory, and Nutritional Properties of Durum Wheat Pasta. Foods 9, 354. https://doi.org/10.3390/foods9030354

Troilo, M., Difonzo, G., Paradiso, V.M., Pasqualone, A., Caponio, F., 2022. Grape Pomace as Innovative Flour for the Formulation of Functional Muffins: How Particle Size Affects the Nutritional, Textural and Sensory Properties. Foods 11, 1799. https://doi.org/10.3390/foods11121799

Yalcin, E., Ozdal, T., Gok, I., 2022. Investigation of textural, functional, and sensory properties of muffins prepared by adding grape seeds to various flours. J. Food Process. Preserv. 46. https://doi.org/10.1111/jfpp.15316

Yang, C., Han, Y., Tian, X., Sajid, M., Mehmood, S., Wang, H., Li, H., 2022. Phenolic composition of grape pomace and its metabolism. Crit. Rev. Food Sci. Nutr. 1–17. https://doi.org/10.1080/10408398.2022.2146048

Zak, D., Roth, C., Unger, V., Goldhammer, T., Fenner, N., Freeman, C., Jurasinski, G., 2019. Unraveling the Importance of Polyphenols for Microbial Carbon Mineralization in Rewetted Riparian Peatlands. Front. Environ. Sci. 7, 147. https://doi.org/10.3389/fenvs.2019.00147

Zeb, A., Ullah, F., 2016. A Simple Spectrophotometric Method for the Determination of Thiobarbituric Acid Reactive Substances in Fried Fast Foods. J. Anal. Methods Chem. 2016, 9412767. https://doi.org/10.1155/2016/9412767

Zhang, Z., Fan, X., Yang, X., Li, C., Gilbert, R.G., Li, E., 2020. Effects of amylose and amylopectin fine structure on sugar-snap cookie dough rheology and cookie quality. Carbohydr. Polym. 241, 116371. https://doi.org/10.1016/j.carbpol.2020.116371

Zhou, D.D., Li, J., Xiong, R.G., Saimaiti, A., Huang, S.Y., Wu, S.X., Yang, Z.J., Shang, A., Zhao, C.N., Gan, R.Y., Li, H.B., 2022. Bioactive Compounds, Health Benefits and Food Applications of Grape. Foods 11. https://doi.org/10.3390/foods11182755