Current Food Science and Technology Reports (2024) 2:7–16
https://doi.org/10.1007/s43555-024-00020-0

Use of Grape Pomace from the Wine Industry for the Extraction of Valuable Compounds with potential use in the Food Industry

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Accepted: 8 January 2024 / Published online: 26 January 2024

Abstract

Purpose of Review This review explores the importance of grape cultivation, as well as the generation of waste in the wine production process, the characteristics of the waste material, and the current uses of this agro-industrial waste; the extraction of the compounds of interest is also addressed as well as a review of the patents related to the subject to finally expose the challenges of the use of waste from the wine industry.

Recent Findings In recent years, the concept of circular bioeconomy has considered agro-industrial wastes as a natural source of bioactive molecules. The wine industry generates a wide variety of waste; of the 75 million tons of fruit produced annually, 80% is destined to different wine production. The residues generated after wine production are abundant and can also be a source of various bioactive compounds. The main compounds include high cellulose and hemicellulose content, polyphenolic compounds such as flavonoids, anthocyanins, and catechins, and oils present in the seeds. All of these components can be recovered and used as ingredients and additives in the food industry.

Summary The wine industry in Mexico is the second-largest source of employment in the agricultural sector, with a production of approximately 450,000 tons per year (according to the Mexican Wine Council). Like other industries, the wine industry generates wastes during the process of transforming raw materials. These residues have a rich composition of compounds, making their extraction and use desirable. Depending on the stage of the winemaking process, the chemical composition of these materials may vary, which diversifies the opportunities for recovery and application of the different fractions. The compounds that can be recovered are polyphenolic compounds such as catechins, quercetins, anthocyanins, and resveratrol. The richness of these residues makes it desirable to take advantage of them through various extractive methods to later incorporate them in new food formulations or in the pharmaceutical industry.

Keywords Grape marc · Bioactive compounds · By-products · Green extraction · Antioxidants

Introduction

The grape is a fruit of great importance worldwide; it is processed mainly for transforming into wine through crushing and fermentation [1]. The wine industry encompasses all activities related to grape cultivation, wine production, and marketing. In addition, it is a sector with significant economic impact. The winemaking process is divided into stages such as harvesting, crushing, maceration, fermentation, maturation, clarification, and bottling for sale. It is important to note that the wine industry produces high amounts of residues [2]. To produce 750 l of wine, approximately 1000 kg of grapes are needed, generating 120 kg of pomace, which represents 60% of the total solid waste [3]. The elimination and incorrect treatment of agro-industrial waste negatively impacts social, economic, and environmental, which generates a problem due to the contamination of the soil, water, and greenhouse gas emissions that contribute to global warming and climate change [4]. The industry seeks to convert waste to transform it into beneficial value-added products. The use of grape pomace is an alternative to reduce waste, improving sustainability and circular economy. Grape pomace contains up to 70% bioactive compounds such as phenolic acids, flavonoids, and tannins, known for their antioxidant capacity, protecting cells from oxidative stress by free radicals [5, 6]. Studies have shown

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that agro-industrial residues have nutritional and functional potential with biological properties [7]. Among the bioactive properties of this waste, its antimicrobial, antiviral, antiaging, antiallergic, and anticancer activity stands out [8]. The bioactive extracts of pomace can be extracted by different methods, such as extractions using organic solvents, extractions assisted by enzymes, and the use microorganisms through fermentation. Likewise, these compounds have many applications in the food industry [9•, 10]. The extract is rich in antioxidants and beneficial compounds to improve product quality, extend shelf life, and fortify nutritional value. Among the most common uses is its use as a source of dietary fiber and antioxidants, having two favorable effects such as increasing fiber content and delaying oxidation in food during storage [11]. In addition, it is used as a colorant for bakery and grape pomace is also reused for livestock feed [12]. This review presents grape pomace's main components and applications to promote its valorization in the food industry as a sustainable and profitable alternative to obtain antioxidants and bioactive compounds.

Economic Importance of Grape Cultivation Worldwide and Waste Generation

The wine industry has acquired notable importance in the agro-industrial field worldwide. The grape is considered one of the most prominent fruit crops [13]. Grape production was estimated at 77.8 million tons of fresh grapes in 2018, of which 27 million were destined for table grapes production (36%), and approximately 1 million for raisin production (7%). The remaining 57% is used for winemaking. According to the Statistics Unit of the International Organization of Vine and Wine (OIV), grapes are the world's leading fruit. Countries such as Spain, China, France, Italy, and Turkey have vineyard areas dedicated to grape production, contributing to 50% of the total global grape [14]. The cultivation of grapes has an important role in the economy due to different factors that benefit various economic areas, as shown in Fig. 1, highlighting the market value. Therefore, grapes are a widely demanded crop to produce wine and other derived products [15]. In addition, it is essential to note that the wine industry can export products to international markets, which generates employment and income, favoring economic development [16].

It is important to mention that just as the wine industry has benefits, it also has disadvantage, such as the generation of agro-industrial waste, particularly grape pomace and grape stems. The higher the concentration of these wastes, the more toxic or anti-nutritional compounds they can generate, limiting their application. The disposal of these wastes can pose a considerable environmental problem [17•]. Global concern for the reuse of agro-industrial waste has gained significant impulse in the scientific community and in the industrial sector, where transformation processes generate waste with added value. This is where the circular economy of agro-industrial waste intervenes, which can implement a systematic approach for efficient recovery. Biotechnology allows taking advantage of compounds such as polyphenols, catechins, proanthocyanidins, resveratrol, ellagic acid, gallic acid, dietary fiber, essential fatty acids, vitamins, minerals, and anthocyanins; these compounds

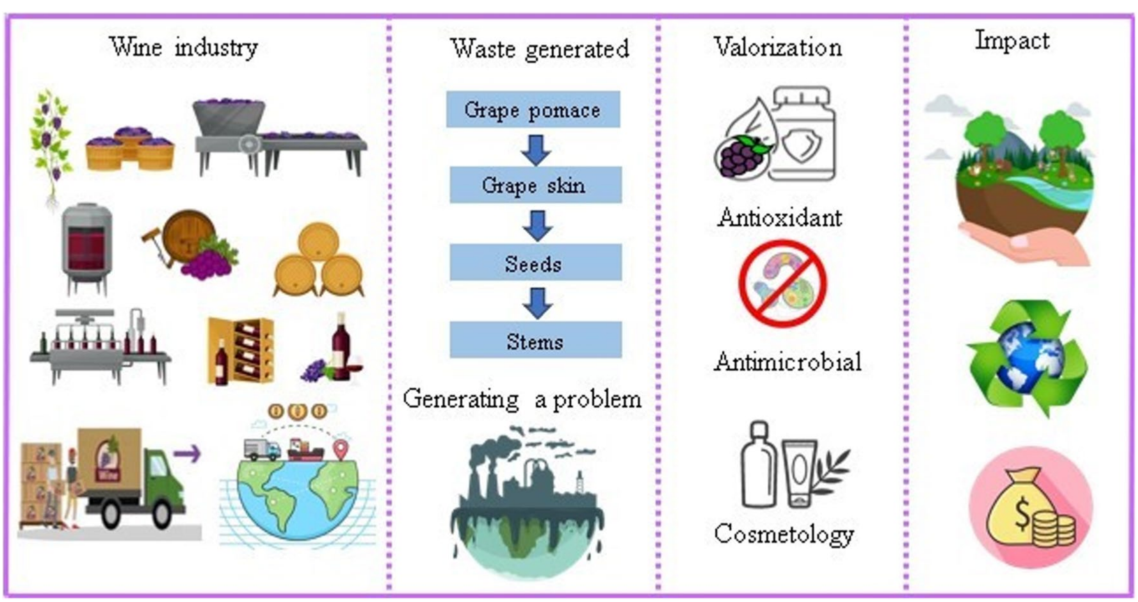

Fig. 1 Economic importance of cultivation and recovery of waste from the wine industry

have nutritional and beneficial properties for health due to its antioxidant, anti-inflammatory, and cardiovascular properties and allow the development of innovative products such as encapsulated antioxidants from grape pomace [18]. It can also be used as a nutritional supplement to provide the nutrients in the daily diet, preventing nutrient deficiency and contributing to improve to general health and well-being [19]. In the cosmetic industry, extracts from wine residues can be used as a skincare cream, protecting against premature aging and contributing to a better appearance and health [20]. Grape pomace has been shown to possess antimicrobial properties, providing empirical and affordable solutions/alternatives that could potentially be used in animal feed. [21]. Therefore, the recovery of waste from the wine industry has promising applications to expand its study due to its bioactive composition, with innovative products in industries, improving their competitiveness in the increasingly demanding global market and seeking strategies to benefit the sector, minimizing the negative impact on the environment, and promoting sustainable development.

Characteristics of Wine Industry Wastes

The characteristics of waste from the wine industry can vary depending on the production process and the methods used by each winery. Wastes generated by the wine industry can be divided into waste obtained from the agricultural part of the process and waste obtained within the wine production process; the vine shoot is the waste obtained from the agricultural part of the process; the stems, grape pomace, and wine lees are the waste obtained within the process part. Figure 2 shows the stages of winemaking.

The vine shoot comprises leaves and tendrils; it is the primary unit of vine growth obtained from vine pruning; about 1–2 tons per hectare are obtained per year [22]. Leaves are the most visible parts of the plant canopy and are formed by the petiole (provides structure) and the leaf blade (absorbs light and CO_2). Reports have indicated the presence of different types of compounds, including stilbenes, hydroxycinnamic acids, hydroxybenzoic acids, flavan-3-ols, anthocyanins, flavanones, flavonols, flavones, and coumarins [23].

Grape pomace is composed of skin, seeds, pulp, and stems. It is the residue that is obtained in the highest proportion, around 60–50% w/w of the total weight of the grape, and it is also the most studied residue of this industry. The composition of grape pomace may vary depending on the vinification process, variety of grape, and the different environmental conditions of cultivation. Proportion of skin, seed, and pulp present in the residue varies by the wine production process, since it can be obtained directly by pressing the grape or it can have a previous fermentation, and the type of inoculum. The skin and pulp are a rich source of phenolic compounds (catechins, quercetins, anthocyanins), as well as a rich source of fiber. The seed contains essential fatty acids (linoleic acid), phenolic compounds (phytosterols), and antioxidant compounds (vitamin E).

Stems are formed due to the peduncle that extends outward to support the fruit of the vine and represent 7% w/w of the total weight of the grape. The decision to remove or retain the stems in the process is made because of the astringency it brings to the wine [24]. Astringency is due to the presence of several types of compounds, including hydroxycinnamic acids, flavan-3-ols, flavanones, flavonols, and lignocellulosic compounds such as hemicellulose, cellulose, and lignin.

Wine lees, the sediment that forms during the alcoholic fermentation process, during storage, or after treatments, represents 5% w/w of the total weight of the grapes and is composed of a liquid phase and a solid phase; the liquid phase contains mainly ethanol and organic acids (lactic acid and acetic acid) [25]. The solid phase contains mainly yeast cells, phenolic compounds, organic acids (tartaric acid), and insoluble carbohydrates [25]. Table 1 shows the characteristics of industrial residues. The wide variety of compounds that can be obtained from this waste can be used in the food, cosmetic, medical, biofertilizer, and energy production industries.

Grape residues after the wine production process have a high content of compounds that can be used, among which the most important is the high content of lignocellulosic material for grape pomace and wine shoots; these residues also have the highest fiber content. Grape pomace stands out for its high content of essential oils and wine lees have an important protein content that can be used in the food industry.

Main Uses of the Waste

As described, the presence of valuable components in this type of material makes its use desirable due to its abundance in bioactive compounds. Therefore, it can highlight the potential use of the residue or its by-products in different sectors such as food, cosmetics, and pharmaceuticals for their antimicrobial and antioxidant properties [32]. Figure 2 shows the winemaking process, indicating where the main residues are obtained and their applications. Among the valuable compounds, polyphenols stand out, and the main compounds identified can be divided into four categories: phenolic acids (hydroxybenzoic and hydroxycinnamic acids), flavonoids (flavones, flavanones, flavanols, isoflavones, anthocyanins), tannins (procyanidins), and stilbenes (resveratrol) [9•]. Numerous research studies are related to the benefits of these compounds for their antioxidant, anti-inflammatory, antimutagenic, anticarcinogenic, and anticancer activities.

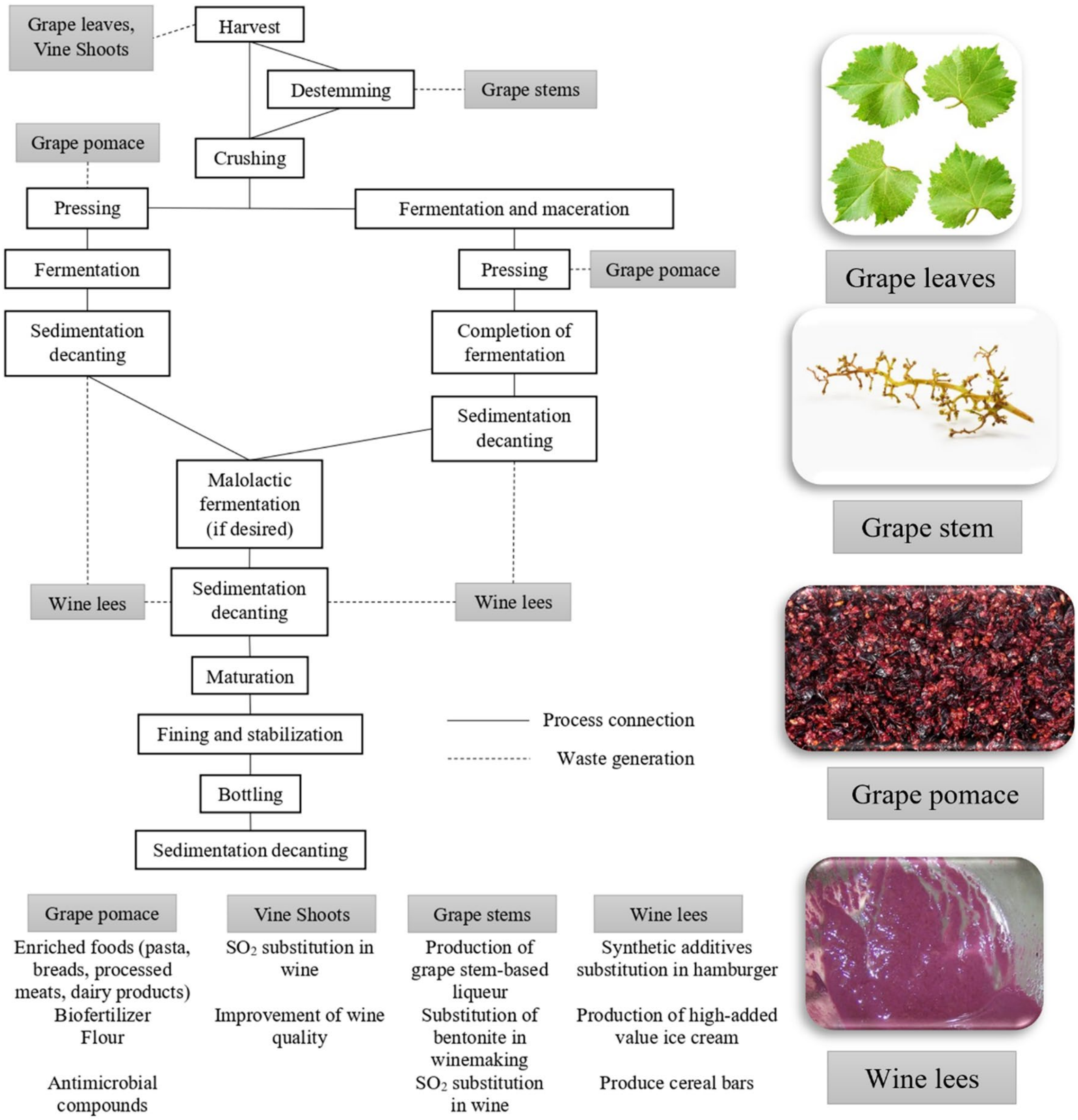

Fig. 2 Main stages of winemaking, waste generated, and its application

Different preparations have been tested in food manufacturing using raw material wastes to be used by the food, cosmetic, and pharmaceutical industries as a supplement or additive. Monteiro et al. [33] prepared different bakery products with wheat flour, substituting concentration on wheat flour with flour prepared with grape pomace, trying not to alter its sensory characteristics and to obtain a functional food. In addition to incorporating grape pomace into food processing, the utilization of other residues for the same purpose has been tested [34]. Pundhir et al. [35] added wine lees in the production of low-calorie ice cream; adding 25 g of lees/kg ice cream improved the physical and rheological properties of the ice cream; a positive response was obtained from those consumers who require low-sugar ice cream, and additional benefits were obtained with antioxidant-rich ice cream. Alarcón et al. [36] used wine lees as a natural preservative for deer hamburgers, replacing sodium ascorbate. The addition of 5% produced a reduction in pH and a greater antioxidant capacity, less oxidation of lipids and proteins, and inhibition of aerobic psychrotrophic bacteria and enterobacteria during storage time. However, the presence of volatile compounds (esters, acids, and benzenic compounds) produced new odor and taste attributes including a “roast beef” odor, “raisin” flavor, and “wine” flavor. These new attributes were considered pleasant at low intensities when rated by the panelists. In addition to the properties that the compounds contained in wine lees can provide, it is a considerable source of protein due to the yeasts derived from the fermentation process, which can be added

Table 1 Characterization of industrial residues in wine industry

Residue	Grape	Carbohydrates (g/100 g)	Protein (g/100 g)	Ashes (g/100 g)	Fiber (g/100 g)	Lipids (g/100 g)	References
Grape pomace	*Vitis vinifera* cabernet sauvignon	-	2.12 ± 0.44	6.72 ± 0.023	27.75 ± 0.25	-	[26••]
	Vitis vinifera Syrah	Total 50.53 ± 3.57 Lignin 46.70 ± 1.78	10.04 ± 0.08	7.22 ± 0.10	17.55 ± 0.75	9.30 ± 0.31	[27]
Vine shoots	*Vitis vinifera* Hondarribi Zuri	Glucan 33 hemicellulose 27 lignin 26.7	-	2.6	-	-	[28]
Grape stems	-	-	7.80		77.2	-	[29]
		pH	**Protein (g/100 g)**	**Ashes (g/100 g)**	**Lipids (g/100 g)**	**Compounds**	**References**
Wine lees	*Vitis vinifera* Tempranillo	3.380 ± 0.050	0.855 ± 0.025	33.283 ± 0.171	0.132 ± 0.047	Undecylic acid, palmitic acid, linolenic acid, eicosadienoic acid	[30]
	-	3.41 ± 0.01	21.2 ± 3.4	10.27 ± 0.05	0.07 ± 0	Tartaric acid	[31]

in the formulation of cereal bars. By adding 5% of concentration of autolyzed biomass, the protein content increased and a positive consumer response was obtained [37].

Different applications have been sought for this type of waste [38]. The development of the circular economy allows the implementation of each waste; sulfur dioxide (SO_2) is used as a preservative agent in wines for its antioxidant and antimicrobial properties, to change the use of this component without compromising its quality. The implementation of residues from pruning or the destemming process, which have similar properties, has been studied, allowing substitution as a preservative agent. In winemaking, the use of bentonite for the clarification of white wines is common due to its interaction with proteins; however, the interaction is not totally specific, eliminating aromatic compounds in the process, reasons that contribute to the loss of sensory quality and for which wineries seek to minimize its use, so the use of extracts obtained from recovered stems represents a valuable agent to eliminate unstable proteins in the wine, thus modifying protein precipitation [39].

Extraction of Bioactive Compounds from Grape Pomace

The search for natural additives involves a scientific area well studied in the last decades; several studies have analyzed and reported new remarkable sources of bioactive compounds in plants, fruits, and microorganisms. However, the current situation (human growth, food demand, overproduction, global warming, among others) has redirected the scientific approach to the change of the conventional lineal production economy to a circular economy, with the incorporation of by-products into the production line and reduce the waste production. The chemical evaluation of by-products as a source of novel molecules englobes a remarkable approach, where the grape pomace could be studied. According to Balli et al. [40], the residual material still contained bioactive molecules per dry weight (DW) as flavonoids (290.6 mg/kg DW) and quercetin (158.5 mg/kg DW). However, the extraction yields, chemical stability, and functional properties will be related with the technology applied to the by-products. This section will be focused on phenolic compounds and oil as they englobe the mainly bioactive compounds in grape pomace.

Modern Extraction Technologies

A critical point in the recovery of bioactive compounds is the extraction technique (ET) selection since the ET will have a negative or positive impact on chemical stability, functionalities, and toxicity, besides the climatic effect by energy consumption, heat production, and residues. It is well known that a wide range of technologies have been developed to improve conventional procedures (liquid extraction, percolation, organic solvent extraction, among others). Technologies such as ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE) have been the most applied "emerging technologies" in the last years [41]. However, technological development has allowed the appearance of new extraction procedures. For example, the technologies that applied higher pressures could be a novel approach; a study by Pereira et al. [42] showed remarkable results in the recovery of monomeric anthocyanins and the concentration of total phenolic compounds using pressurized liquid extraction (PLE) on the grapes. Also, the data suggest that different conditions promote the extraction of different anthocyanins (ethanol: water, pH 2.0, 50% w/w, 40 °C) and phenolic compounds (ethanol: water, 50% w/w, 100 °C). Similarly, Perra et al. [43] studied the application of PLE into grape by-products as a circular economy model by response surface methodology (RSM) and the results showed a maximum phenolic extraction (130 °C, 55% ethanol and 22 min). Thus, applying PLE could be an alternative for the recovery of bioactive molecules.

Also, the pulsed electric field (PEF) is an extraction method applied to recover bioactive molecules. The PEF and supercritical CO_2 extraction has been evaluated in grape seeds for the oil recovery; the technological combination obtained a higher extraction yield (81.8 ± 1 g/kg) than the conventional method "cold pressing" (67.1 ± 0.2 g/kg). In addition, the data suggest the possibility of a more selective extraction procedure of sterol and nonflavonoid fractions than the conventional method [44]. A similar protocol was developed by Salgado-Ramos et al. [45] in grape pomace; their findings showed higher recovery of bioactive glycosylated and lipidic compounds with antioxidant activity (68%) than the conventional soaking method.

Finally, another emerging technology is enzymatic assisted extraction (EAE). The EAE could be applied by individual application of enzymes. Ferri et al. [46] evaluated cellulolytic enzymes (xylanase, pectinase, and cellulase) to extract phenolic compounds from grape pomace followed by extraction with acetone; the study showed an effective way to increase the extraction yields by the hydrolyzing the material (11% higher). Otherwise, as an alternative, the application of microorganisms with the capacity to produce required enzymes englobes a well-studied technology in recent years; for example, the solid-state fermentation (SSF) is a technology applied in several by-products for the recovery of bioactive compounds [26••]. In the case of grape pomace, Amaya-Chantaca et al. [26••] studied the application of *Aspergillus niger* GH1 as a biological model; the results showed the release of 2.262 g/L and 3.684 g/L hydrolyzable and condensed tannins, respectively; the authors associated the extraction with the production of tannase, ellagitannins, β-glucosidase, among other enzymes identified in the process.

The extraction technologies cover a critical point for the valorization of waste material, and the new advances offer modern alternatives and research lines of research in the search for sustainable processes in the food industry.

Recent Patents in the Food Industry

A world intellectual property database (PATENTSCOPE https://www.wipo.int/patentscope/en/) has been applied to search the technological growth in extraction technologies in grape pomace. According to the search made in "WIPO-PATENTSCOPE" (accessed July 10, 2023) using the keyword "Grape pomace" and "extraction," 4 patents were registered in a period between 2021 and 2023, and the databases reported a registration of up to 6 related patents, in the last 2 years (Table 2). Highlight that China has published all recent patents according to the world intellectual property database.

Cluster Distribution of Research Information in Grape Pomace

The VOSviewer englobes a novel tool for mapping the bibliographical information and graphical representation according with the similitudes by keywords; the analysis determined current research in grape pomace topics (2014–2022); the findings organized the recent research information in 5 cluster (Fig. 3a). The first cluster (red called *Valorization approaches of grape pomace*) englobes research articles mainly related with "Fermentation," "Biodegradation," and "Solid state fermentation"; the second cluster (green called *Extraction technologies and components*) is related to the "extraction," "solvents," and "chemical identification"; the third cluster (blue called *Metabolism/bioactive interactions*) is related with bioactive interactions or properties as "antioxidant activity," " Diet supplementation," and "Drug effect"; the fourth cluster (Yellow called *Chemical components*) involves keyword related with chemical components as "Catechin," "Gallic acid," and "Chlorogenic acid"; finally, the fifth cluster (violet called *Microbiological interactions*) englobes keyword related with microbiological interactions with keyword "Prebiotics," "Pathogenic bacteria," and "Functional foods." Thus, the first graph represents the current information available in bibliographical reservoir in the last 8 years.

Also, an analysis of trends across the time (Fig. 3b) was applied to define the recent research areas; it showed that the first and third cluster (Valorization approaches of grape pomace and Metabolism/bioactive interactions) encompasses more recent studies (yellow = > 2022) and the other clusters revealed more studies between 2014 and 2020; according to the obtained information, recent trends are more focused on valorization technologies, integration of biological techniques, and biological property evaluation, beyond the chemical characterization or extraction techniques development.

Challenges in the Area

However, grape residues generated from the winemaking process constitute a rich source of compounds with a high potential for application in various industrial areas,

Table 2 Recent patents related to extraction methods in grape pomace

Patent number	Title	Main core	Scope	Publication data	Country
CN216855738	Dynamic countercurrent extraction device for the pigment of grape pomace	The inventions consist in a reasonable structural design for pigment extraction, and the reaction speed of grape skin residues is increased; on the other hand, the grape skin pomace is extruded and stirred in time so that the reaction speed of the grape skin pomace is increased (mechanical automatic operation); the working efficiency is greatly improved	Industrial design	01.03.2022 [47]	China
CN21423284	Self-suction type extraction device for extracting grape skin pomace anthocyanidin	The utility model discloses a self-suction type of extraction device for extracting grape pomace anthocyanidin	Industrial design	21.09.2021 [48]	China
CN115504863	Method for extracting resveratrol from grape pomace by enzymolysis/two/phase acid hydrolysis coupled aqueous two-phase extraction technology	The method comprises the following steps: treating grape pomace by adopting enzymolysis and two-phase acid hydrolysis methods, decolorizing, evaporating, crystallizing, centrifugally separating, and drying to obtain white crystal trans-resveratrol	Chemical extraction	23.12.2022 [49]	China
CN114836258	Method for extracting grape seed oil from grape seed after wine brewing	The invention discloses a method for extracting grape seed oil from wine-brewing grape seeds, which comprises the following steps: (1) separating wine-brewing grape skin residues; (2) carrying out subcritical extraction on the grape seed powder and collecting an extract; and (3) carrying out ultrasonic cell disruption on the extract, filtering to obtain grape seed extraction oil	Chemical extraction	02.08.2022 [50]	China

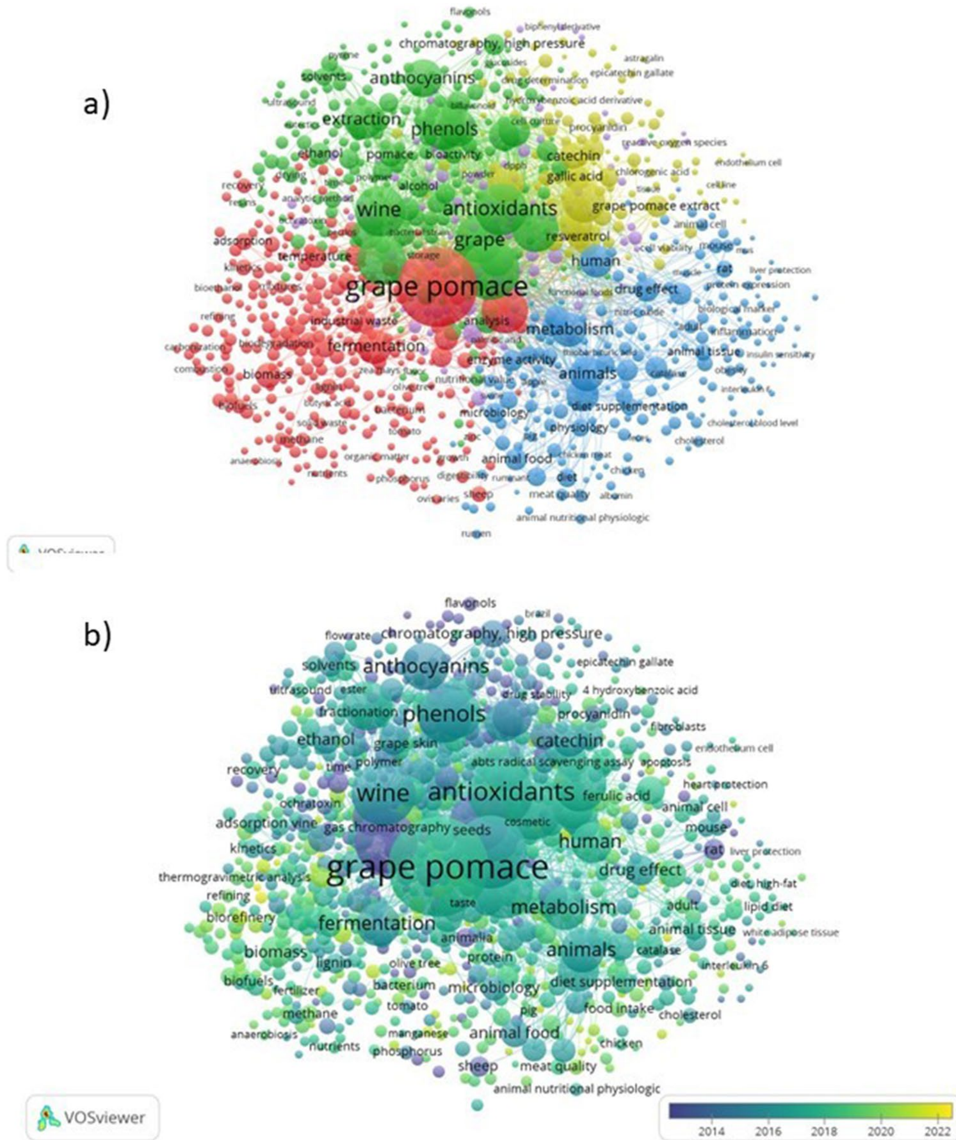

Fig. 3 Network graph of grape pomace 2018 to 2022 by VOSviewer. **a** Cluster distribution of research information in grape pomace trends; **b** time distribution of research information in grape pomace between 2019 and 2022

particularly in the food industry. There are multiple challenges to achieving efficient use of these materials. The first of these is the correct disposal of the waste generated and the generation of better logistics systems that allow for adequate collection of the materials to avoid immediate deterioration.

In recent years, there has been a deep interest in establishing processes under the concept of circular economy, which seeks to make processes more efficient, highlighting the maximum savings of resources and promoting sustainability, where one objective is to have zero waste and aims strategies for the recovery of compounds that have an added value; there are several extractive techniques developed and focused on the recovery of these types of compounds contained in grape pomace; however, most of them do not contemplate a scaling-up strategy and at this point, many of the options are limited. It is necessary to establish studies that allow scaling up as a necessity if the developments are to be commercialized.

An important part in the valorization of these wastes is the separation and purification of the fractions rich in bioactive compounds, which constitutes a technological challenge to generate low-cost strategies.

Final Remarks

The residues generated during wine production are a rich source of raw material with high bioactive potential mainly associated with their potent antioxidant activity. Numerous strategies exist for the extraction and recovery of these components; however, considerable efforts must be made to develop strategies for scaling up the recovery of the components as well as their purification process.

The use of grape pomace is an alternative for the generation of commercial value chains that allow a sustainable use of natural resources and the generation of raw materials under the concept of circular economy.

Author contributions Authors' contributions: ASS: data analysis, writing, revision. KALS: writing, review and editing. IBH: data analysis, writing, editing. MLCG: Conceptualization, methodology, data analysis, writing, discussion, and editing. All authors reviewed the manuscript

Declarations

Competing Interests The authors declare no competing interests.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by the authors.

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- • Of importance
- •• Of major importance

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