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Exploring grape pressing for sparkling wine production: A comprehensive literature review on physicochemical parameters and technological applications

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ABSTRACT

The pre-fermentative steps play an important role on the characteristics of white wine. Among them, the grape pressing is a crucial phase as the extraction of grape compounds occurs having a relevant impact on the composition of must and, consequently, of wine. The grape pressing is particularly important for the sparkling wine production as it influences the acidity and phenol concentration of must.

The aim of this review was to explore the must changes occurring during grape pressing. The pressing technologies and conditions were discussed and compared, considering their impact on must composition. Special attention was devoted to the pressing of grape for obtaining must addressed to sparkling wine production, considering the challenges for preserving the acidity and managing the extraction of phenolic and aromatic compounds. Hence, the current awareness and the gaps of knowledge are presented and discussed.

Pressing grapes for white and sparkling winemaking requires a controlled approach to maintain must integrity and ensure the quality of the final product. High constraints on solid parts mean higher extraction of phenolics, aroma precursors and potassium. The latter, causing the precipitation of tartaric acid, leads to a pH increase and acidity decrease. Higher extraction of phenolics can make the must and the wine more susceptible to oxidation. Different conditions adopted in terms of grape temperature, oxygen exposure, applied pressure, fractioning and types of press affect the composition of must. Future researches on this step should also consider the grape composition.

1. Introduction

The International Organization of Vine and Wine (OIV) defines the wine as “the beverage resulting exclusively from the partial or complete alcoholic fermentation of fresh grapes, whether crushed or not, or of grape must” (OIV, 2024). The two major production processes include the red and white winemaking differing for the maceration step which is not performed in the last case. Moreover, considering the white winemaking, the grape must is obtained by pressing the grape bunches or the destemmed grapes. In any case, the maintenance of wine quality is a relevant feature for both winemakers and consumers being determined by several complex factors, including the grape variety, viticultural practices, winemaking techniques, and *terroir*. The latter is a large concept combining grape cultivar, growth characteristics and area, and pedological factors as well as specific soil, topography, climate, landscape characteristics and biodiversity features (Anastasiadi et al., 2009; Kupsa et al., 2017; Parpinello et al., 2019; OIV, 2024). Not at last, the climate conditions affect the grape ripening and, consequently, the wine characteristics, as structure, acidity, balance of chemical composition, and maturation potential (Conde et al., 2007).

Taking into account the overall wine production, the harvest should be carried out when the ideal grape maturity has been reached that is affected by many factors, including grapevine cultivar, soil, vineyard management (e.g. row orientation, defoliation, nourishment), hormonal regulation (Van Leeuwen et al., 2009). At the winery level, focusing on white winemaking, the pre-fermentative operations play a relevant impact on the characteristics of must and, consequently, of wine (Darias-Martín et al., 2004). Grape pressing is one of the most important pre-fermentative steps, since it influences must characteristics being affected by different pressing methods and must yields (Ferreira-Lima et al., 2016). The main aims of pressing are to extract a proper amount of grape juice, limiting the loss of liquid and the presence of suspended

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solids, to produce a must which composition allows to obtain a high-quality white wine with balanced chemical and sensory characteristics. Nonetheless, the desired peculiarities of wine should be preserved the during the shelf life (Gawel et al., 2014).

Due to the relevant importance of the grape pressing, this review is focused on (i) the main outcome and chemical changes of must occurring during the pressing, (ii) some of the equipment used for the pressing of white grape, and (iii) the conditions of performing the grape pressing. Moreover, (iv) a particular attention will be given to the pressing for the must addressed to sparkling wine production. The actual awareness and the lack of knowledge are critically presented and discussed.

2. The production of white must

The white winemaking consists of carrying out the alcoholic fermentation of grapes or must which production requires the selective extraction of grape components. The latter includes the desired parts of grape berries positively affecting the chemical (e.g., compounds less susceptible to oxidation) and sensory (e.g., acidity, astringency, bitterness) balance. The diffusion in the liquid phase of those detrimental grape components should be limited as they can be responsible of olfactory and gustatory flaws (Ribéreau-Gayon et al., 2021). The careful management of pre-fermentative operations is a fundamental requirement for setting a winemaking process with limited inputs, so increasing the sustainability of the wine production chain (OIV, 2020b).

The production of white wine has increased in 2021 (+13 % from the lowest level observed in 2002) being higher than the production of red wine since 2013. This increase has been driven by the production of sparkling wine. In the period 2000-2021, Italy has been the major white wine producer worldwide (29.4 mhl), followed by France (18.4 mhl) and Spain (17.4 mhl) within Europe, and USA (13.5 mhl), South Africa (6.6 mhl) and Australia (6.3 mhl) in a global vision. The top three countries in white wine consumption have been the USA (18.3 mhl), Italy (14.2 mhl), and Germany (8.4 mhl) (OIV, 2023). This data evidences the importance that the white wine has worldwide and the need of the improvement of its production starting from the pre-fermentative steps.

In general, obtaining a high quality must is important for both the fermentation process and the quality of wine. The pre-fermentative operations play a relevant impact and winemakers are always aware of the pre-fermentative techniques to achieve the desired results (Patel et al., 2010). Among the pre-fermentative steps, the pressing has an important role in the production of a must. Several chemical/physical characteristics of must are influenced by the grape pressing, (described in detailed in Section 3). As example, the pressing can affect the extraction of phenols that is strongly dependent on the management of the contact of the liquid must with the solid parts of the grape bunches as well as on the grape variety (Maggu et al., 2007).

The general principles to obtain a white must with adequate chemical/physical features include low pressing pressure, slow and progressive increase of pressure, high volume of juice extracted at low pressure, low extraction temperature (lower than 20 °C), limited mechanical damage of grape skins, limited crumbling or press-cake breaking and minimum air contact (Ribéreau-Gayon et al., 2021). Therefore, the appropriate use of pressing machines demands knowledge of the conditions affecting the extraction yield and must quality, minimizing pressing time, obtaining a grape must with low turbidity, and extracting the minimum levels of phenols; in particular, the latter is required for the specific types of wine (e.g., sparkling wine) (Darias-Martín et al., 2004). The selection of processing techniques in terms of pressing variables, as temperature, pressing gradient and air exposure (deeply discussed in Section 4), can affect the composition of must and, consequently, the final quality of wine (Fig. 1).

When grapes are subjected to pressure, the aliquot of juice most easily released is from the weakest pulp cells of the grape intermediate zone (exocarp and mesocarp); the juice is then obtained from the central and peripheral zones of the grape berry by continuing the pressing (Ribéreau-Gayon et al., 2021). As shown in Fig. 2, the different concentrations of the grape compounds are allocated in different parts of the berry. The application of a pressing program working in a step-by-step pressure increase, allowing the progressive extraction of must, leads to the first fraction of must being from the intermediate zone juice that is richer in sugars and tartaric acid (Ribéreau-Gayon et al., 2021). The fraction obtained thereafter, from both the central and peripheral zones, is richer in malic acid, phenolic compounds and salts. This is because the peripheral zone contains mineral salts, potassium, primary aromas, and phenolic compounds that are majorly extracted by continuing the pressure application with a possible impact on the development of oxidative mechanisms as well as on perception of bitterness and astringency. For this reason, it is important to find out the equilibrium for the adequate extraction of these grape components, taking into account the desired final composition and style of wine (Catania et al., 2019a). An adequate amount of aromas and their precursors, especially for aromatic grape varieties, should be present in the must to ensure the desired aromatic potential of the resulting wine (Gawel et, al.,2014). In case the applied pressure is excessive, seeds and stems can also be

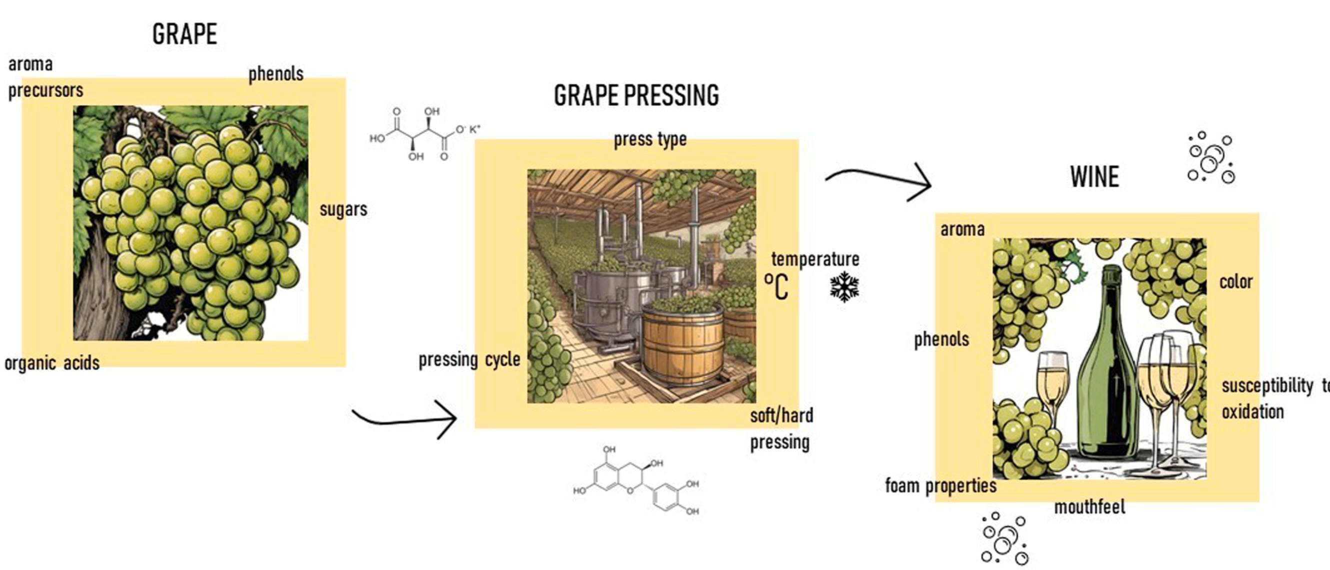


Fig. 1. Compounds and conditions affecting the pressing.

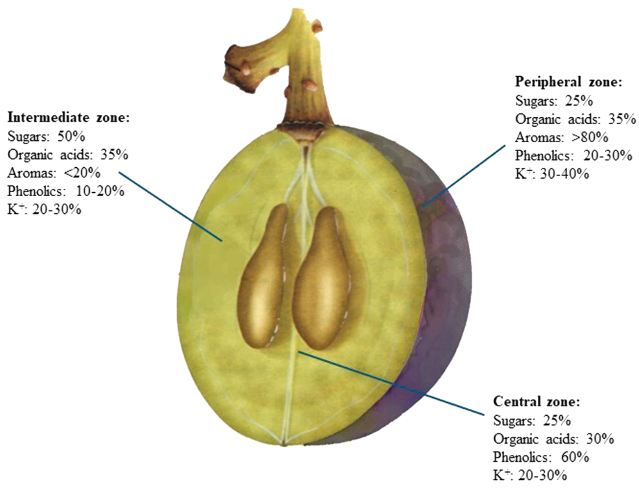


Fig. 2. Grape berry structure (re-elaborated from Fontes et al., 2011; © 2011 American Society for Enology and Viticulture).

squashed. The seeds contain essential oils and a large part of the catechins and proanthocyanidins responsible for bitterness, and may release fatty substances responsible for unpleasant grassy notes (Jackson, 2008). To produce more flavorful wines with higher phenolic concentrations, winemakers can either press the juice from the remaining wet grape skins after draining or allow the grape skins to remain in contact with the juice before draining (Gawel et, al., 2014) With regards to flavonoids, their extraction is strongly dependent on the management of the contact time between the liquid must and the solid parts of the grape bunches as well as on the grape variety (Mattivi et al., 2002).

3. Impact of pressing on must and wine composition

The heterogenous structure of grape berry (Fig. 2) and the adopted pressing condition are of relevant importance for the composition of must obtained. For this reason, the investigation and knowledge of the chemical and sensory characteristics of the must, produced using different pressing regimes, provide significant and useful information for winemakers (Kerslake et al., 2018). The pressing has bearing especially on the extraction of organic acids and ions, phenols, aroma compounds and their precursors, and proteins.

3.1. Organic acids

Organic acids play a significant effect on the composition, stability, and sensory aspects of musts and wines (Gawel et al., 2014). The main acids found in the grape berries are tartaric and malic, while citric acid is present in minor amounts (Jackson & Lombard, 1993). Tartaric acid is accumulated during the initial stages of berry development and its concentration is highest at the peripheral zone of the berry, while malic acid is mostly present in the intermediate zone (Fig. 2). During the pressing, the increase of pressure leads to a progressive extraction of must: the first fractions are richer in sugars and tartaric acid since they are obtained from the intermediate zone. Instead, the content of malic acid is most abundant in the must fractions collected in the later steps of pressing. Considering organic acids, both the concepts of total acidity and pH should be considered. The OIV defines the total acidity as the sum of the titratable acidities when the titration is carried out to pH 7 against a standard alkaline solution (OIV, 2022). The acidity is a significant character of white wine because it helps to keep the freshness, flavor and, color (Ribéreau-Gayon et al., 2021). A loss of acidity can take place due to the presence of certain ions, specifically potassium and calcium, that are involved in the tartaric acid instability. These ions can salify tartaric acid to generate potassium bitartrate and calcium tartrate, respectively, which have a lower solubility in comparison to tartaric acid. In particular, potassium bitartrate is partially soluble in grape juice and it can precipitate leading to a decrease of the total acidity and an increase of pH. Numerous factors can affect the level of potassium in grape berries including soil potassium content, grape variety, and viticultural practices (Mpelasoka et al., 2003; Davies et al., 2006). The content of potassium is of particular interest for the pressing: differences exist between free-run juice and first press fraction in terms of pH, which is lower in the free-run juice due to the highest content of acids. Darias-Martín et al. (2004) found that once the must extraction was occurring, potassium, being located in the peripheral part of grape berry (Fig. 2), was extracted and its tartaric salts were formed, leading to the pH arise to about 0.3 units. As a consequence, total acidity dropped overall with an increase of pressure.

For the wine industry, a decrease in acidity is a serious concern. The concentration of potassium cations and the pH along with the titratable acidity of musts directly affects the quality of wines. In fact, the decrease of pH causes detrimental effects on the sensory quality of the finished wines. Moreover, wines with high pH values are more susceptible to microbial contamination (Chidi et al., 2018). Therefore, the adequate management of grape pressing and the must fractioning allow to obtain a must with substantial levels of acidity, suitable for the production of white wine and sparkling wine with a desired freshness.

3.2. Phenolic compounds

The phenolics are mostly found in the skin and seeds of the grape berry with negligible concentrations in the juice and pulp (Costantini et al., 2009). The phenolic composition of grape varies depending on both the cultivar and ripening state. Moreover, phenolic content may differ depending on the type of soil, climate conditions (e.g., temperature, rain, humidity), and other biological agents (e.g., fungi, insecticides, fertilizers) (Alvarez-Sala et al., 2000). Both flavonoids (flavonols and flavan-3-ols) and non-flavonoids (hydroxycinnamic acids [HCAs], and hydroxycinnamoyl tartrates [HCTs]) influence color and aromaticity of white musts. Coumaric, caffeic and ferulic acids are the most common non-flavonoid compounds found in grape. Musts richer in hydroxycinnamates can be obtained especially if pectolytic enzymes are used and if the pressing is performed at low temperatures (Gawel et al., 2014).

Kerslake et al. (2018) reported the impact of different pressure on the chemical compositions of must fractions, namely free-run must, light-pressed must (around 0.5–1 bar of pressure) and heavy-pressed musts (more than 1 bar of pressure), and their corresponding wines. The phenolics most affected by the pressure seemed to be caftaric acid, catechin and epicatechin, being detected at higher concentrations in the heavy-pressed must. Since these compounds are located in the grape skins, their extraction was favored by the increase of pressure. Nonetheless, the concentrations of hydroxycinnamates could decrease during the heavy pressing conditions as a consequence of their oxidation, especially if the contact with oxygen is not properly managed (Ferreira-Lima et al., 2016). Moreover, in case high pressure is applied, the breakage of grape berry seeds can also occur furtherly increasing the extraction of phenols, being those leading unpleasant astringent and bitter characters. Despite hydroxycinnamates are generally present in relatively low concentrations (50–200 mg/L), they can be responsible for the browning of musts: non-flavonoid phenolics can be oxidized to *o*-quinones by the polyphenol oxidase (PPO) enzyme in the presence of oxygen (Yokotsuka, 1990; Du Toit et al., 2006; Rolle et al., 2022). Caftaric acid, being extracted during pressing, is rapidly oxidized to *o*-quinones by the PPO enzyme in the presence of oxygen. The *o*-quinones can polymerize into brown compounds negatively effecting the characteristics of white must (Cheynier et al., 1990; Cilliers & Singleton, 1989). The optimum temperature of PPO enzyme is about 35 °C, hence cooler conditions can limit its action. The browning can be prevented if reduced glutathione (GSH), a tripeptide naturally found in grapes and wines, is present. GSH can reduce back the *o*-quinones into the corresponding phenols generating the 2-*S*-glutathionyl caftaric acid, also called Grape Reaction Product (GRP) (Salgues et al., 1986). In this way, the formation of brown polymers can be avoided. The pressing also affects the extraction of GSH as well as of caffeic acid mainly depending on the skin contact time and pressing pressure (Maggu et al., 2007). Moreover, Motta and co-authors (2014) studied the concentrations of reduced and oxidized glutathione in musts collected under various pressing procedures (under air or nitrogen), applying different pressures (first cycle up to 0.6 bar, the second cycle up to 1 bar, third cycle 0.3–1.2 bar, fourth cycle 0.3–1.6 bar) and from different grape varieties (Arneis, Cortese, Moscato bianco, and Manzoni bianco). For pH, titratable acidity, and total sugars, no differences were found between air press and nitrogen press, while significant differences were detected among the total polyphenols and catechins concentrations. Considering the pressing under nitrogen, must from Manzoni bianco grape showed a significantly lower level of total polyphenols and catechins in comparison to that one from Arneis grape, and significantly different catechin concentrations compared to Cortese grape varieties. Pressing under oxygen decreased the average concentration of total polyphenols (−23.7 %) and catechins (−36.3 %). Moreover, the same authors found that color intensity of must increased when the concentration of GSH decreased.

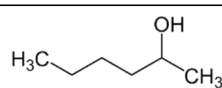
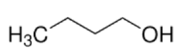
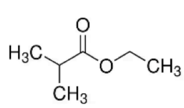
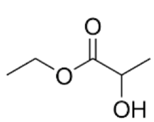
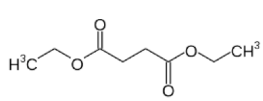
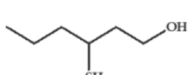
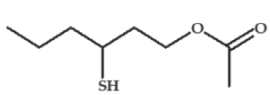
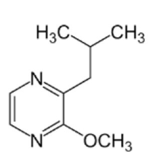
Nonetheless, despite the current knowledge on the phenolic compounds and their role for the quality for grape must or finished wines, the assessment of phenols as quality controls is still fragmented or incomplete, even if they should be considered as a marker for the achievement of an accurate must fractioning.

3.3. Aroma compounds

Wine aroma is made up of various compounds (e.g., higher alcohols, terpenoids, esters, fatty acids, and aldehydes) with concentrations ranging from few ng/L to tens mg/L (Conde et al., 2007). The presence of these compounds is influenced by several factors including the viticultural aspects such as grape variety and terroir, and oenological aspects, such as fermentation, aging and, not at least, pressing (Waterhouse et al., 2016). The aroma compounds discussed in this section being potentially affected by the pressing are reported in Table 1.

Parish-Virtue and co-authors (2021) investigated the pressing of Sauvignon blanc grape under 3 different pressing conditions: free-run (FR) (approx. up to 0.4 bar), light press (LP) (approx. 0.6–1.6 bar) and heavy press (HP) (approx. 1.4–1.8 bar). With regards to the basic wine parameters, the pH increased from FR to HP. Higher pH of pressed juices can also promote oxidation processes and needs to be consider during fermentation, in relation to aroma formation (Roland et al., 2011). For the aromatic compounds, an increase of hexyl acetate, hexanol, and benzyl alcohol was found in the resulting wines, while 3-mercaptohexan-1-ol (3MH) and 3-mercaptohexyl acetate (3MHA) concentration decreased. Similarly, Patel and co-authors (2010) showed that wines produced with musts obtained between 0.25 bar and 1 bar did contain less than the half of the concentration of 3MH and 3MHA, when compared to the wines produced from free-run juice. Instead, the 3-isobutyl-2-methoxypyrazine concentration ranged between 3.7 and 6.2 ng/L. Considering alcohols, hexanol was found as the most abundant C_6 compound and its concentration ranged between 10.2 and 380 µg/L with a significant increase from wines produced with FR to HP. The

Table 1
Aroma compounds potentially affected by pressing process.

Molecule	Chemical structure	Perception threshold	Descriptor	Refs.
Hexanol		1.1 mg/L[a]	Herbaceous, grassy, woody	Peinado et al. (2004)
Butan-1-ol		590 µg/L[b]	Malty, solvent-like	Schnabel et al. (1988)
Ethyl isobutyrate		3.9 µg/L[c]	Fruity, citrus sweet	Blanco et al. (2016)
Ethyl-(L)-lactate		150 mg/L[a]	Fruity, buttery	Peinado et al. (2004)
Diethyl succinate		1.2 mg/L[a]	Fruity, melon	Peinado et al. (2004)
3-Mercapto-hexanol acetate (3MHA)		4 ng/L[d]	Box tree passion, fruit	Tominaga et al. (1998)
3-Mercapto-hexanol (3MH)		60 ng/L[d]	Grapefruit	Tominaga et al. (1998)
3-Isobutyl-2-methoxypyrazine		6.2 ng/L[b]	Bell pepper-like	Mihara and Masuda (1988)

[a] Determined in a solution with ethanol 10 % (v/v) adjusted at pH 3.5 with tartaric acid.
[b] determined in water.
[c] determined in ethanol 25 % (v/v).
[d] determined in ethanol 12 % (v/v).

opposite tendency was showed for the butan-1-ol, the esters ethyl isobutyrate, ethyl-(L)-lactate and diethyl succinate, detected at the highest concentrations in FR fraction wines (Parish-Virtue et al., 2021). Similarly to the phenols, the aroma compounds and their precursors are located in the grape skin which extraction can be favoured by applying a higher pressure and the period of skin contact (Patel et al., 2010).

The impact of pressing on varietal thiol precursors was reported (Fracassetti et al., 2018; Tirelli et al., 2021). Several aspects should be considered during must extraction process to prevent the loss of thiol precursors, such as the addition of sulfur dioxide, the contact time of must and grape solid parts, the presence of copper. The proper management of pre-fermentative steps, pressing included, can allow ro produce must with major levels of thiol precursors potentially leading to a more aromatic wine (Tirelli et al., 2021).

An impact on terpenes was also described in terms of the pressing conditions applied (e.g. juice temperature, blending, skin contact time) (Marais et al., 1986). Specifically, Reynolds et al. (1993) showed that harvest dates, pressing, and skins contact influence on the concentration of free and bound terpenes in the juices and wines produced from different cultivars. The harvest date delay between 10 and 20 days, led to an increased levels of free volatile terpenes (FVTs) and potentially volatile terpenes (PVTs; glycosidically bound) in 3 cultivars out of 6 cultivars investigated. Pressed juices had higher concentration of PVTs. Skin contact for 24, 72 or 264 hours increased the amounts of both FVTs and PVTs in must (Reynolds et al., 1993).

To the best of our knowledge, the impact of grape pressing on the ratio between extraction and depletion of aromas and their precursors has not been extensively investigated yet. This aspect requires further clarification with the purpose to ameliorate the management of pre-fermentative steps and, in particular, of pressing for increasing the aroma potential of must.

Besides the specific aroma compounds, the consumer preferences should be also considered. At this level, aroma, taste, texture, and visual appeal should be taken into account for understanding consumer impact. These attributes evoke specific emotions and memories, influencing consumer preferences and satisfaction. Oyinseye et al. (2022) showed that the wine drinking experience involves an interplay of sensory, emotional, and cognitive dimensions. Danner et al. (2016) reported that high-quality wine evokes more positive emotions compared to lower-quality wines. Additionally, the context in which wine is consumed affects mood and emotions, creating associations between these emotions and a willingness to pay more for the wine, thus increasing purchase intent scores. Apart from specific sensory aspects, consumer willingness (wine neophilia) or reluctance (wine neophobia) to try new wines is important for product innovation and market development in the wine industry. Despite the significant role of neophobia in consumer choice, there is a lack of information on how personality factors affect wine behaviour and the role of neophobia (Pickering et al., 2021). The consumer preferences related to specific pressing conditions were not investigated, yet as well as the impact of pressing on emotions, memories, sensory attributes at the consumer level.

3.4. Proteins

The content of proteins in white wine protein varies between 15 mg/L and 230 mg/L and it can be influenced by grape variety and ripening, climate conditions, and winemaking process (Sauvage et al., 2010). The fermentation temperature as well as the proteins released by *Saccharomyces* and non-*Saccharomyces* yeasts during fermentation can also contribute to the final content of proteins in wines (Mostert et al., 2014). These macromolecules are on particular interest in white wine because they are a possible cause on instability being responsible for the appearance of haziness. Nonetheless, not all the proteins are involved in the wine instability. Thaumatin-like proteins (TLPs) and chitinases, belonging to the pathogenesis-related (PR) proteins, are the two proteins involved into the haze formation (Waters et al., 1996; Ferreira et al., 2001). Therefore, the possible limited extraction by the pressing of these proteins could be on particular interest for the winemakers as lower dosage of bentonite could be used for the wine stabilization. Tian and co-authors (2015) provided additional information on the composition and distribution of proteins in grape tissue in Sauvignon blanc grape. These authors found the major soluble haze-forming PR proteins, TLPs and chitinases were identified in grape skin and pulp, and their presence was not detected in grape seeds.

Tian et al. (2017) showed that the combination of harvest and grape processing conditions have a great impact on grape proteins and phenolics extraction into juice and also affects the wine stability to heat. Destemming and crushing treatment followed by 3 hours skin contact leads to greater extraction of phenolics and proteins from grapes. Machine harvesting with destemming-crushing and 3 hours skin contact led to significantly lower concentrations of proteins, including PR proteins. This could be due to greater juice yield from machine-harvested grape causing also major interactions between proteins and phenolics. The co-extraction of phenolics and proteins is an important aspect to consider for evaluating the possible wine protein stability. Lastly, a positive linear correlation exists between chitinase concentration and bentonite addition for achieving the stability. Hence, a lower chitinase level may require less bentonite for wine stabilization with a positive impact on the sustainability of the wine production chain. By the way, further studies are required for clarifying this relevant aspect.

4. Conditions of grape pressing

The selection of grape processing techniques differing in terms of skin cell disruption, skin contact with the juice and oxygen exposure allows to obtain a variety of white wine styles, having different chemical, physical and sensory characteristics (Boselli et al., 2010). In the context of grape pressing, the combined effect of type of press, temperature, pressing cycle and fractionation of must define the chemical composition of the wines (Del Fresno et al., 2021).

4.1. Equipment for grape pressing

The appropriate use of the pressing machines demands a deep knowledge of the chemical-physical parameters previously discussed and a clear idea related to the desired wine style (Maggu et al., 2007). Nonetheless, the type and choice of press have a direct impact on the chemical composition of wine. Presses can be classified by their operation mode and they can be divided in two categories: discontinuous and continuous presses, which advantages and disadvantages are reported in Table 2.

Wineries with high productivity and volumes can work under non-stop pressing operations by means of continuous screw presses, even if this technology is becoming less and less popular (Jackson, 2008). Continuous presses are constituted by a roller crusher and an Archimedes screw drainer that allow a non-stop pressing process. The speed of the process represents a great advantage and hundreds kilograms of grape can be processed in one minute, leading to high yield of juice, and ensuring a low cost and very flexible management of the pressing step. The most common continuous press in wine production is the screw press that can process up to 50–100 tonnes of grape per hour approximately (Boulton et al., 1996). The constant pitch helicoid screw has the flaw to allow only a constant pressure distribution, lacking in setting or controlling the gradual increase of pressure (Formato et al., 2019). Even if the continuing operating mode and the high volume treated represent the strengths of this equipment, the continuous press does not allow accurate grape pressing with must fractioning. Moreover, continuous press produces colored (towards brownish), vegetal, bitter grape juices with high pH and turbidity, leading to musts and wines difficult to clarify (Ribéreau-Gayon et al., 2021).

For the production of high-quality white wines, slow grape

Table 2
Advantages and disadvantages of continuous and discontinuous presses.

Press machine	Type of press	Pressure	Type of wine	Advantages	Disadvantages	Refs.
Continuous press (screw presses)	Continuous, open	More than 15 bars	Not specified	-High yield (up to 50 ton/h of grapes).	-High mechanical stress on solid parts; -Difficult for clarification; -Higher phenolic contents compared to discontinuous presses working with nitrogen mode.	Boulton et al., 1996; Ribéreau-Gayon et al., 2021
Vertical basket press	Discontinuous, open	Up to 14 bars	Listan blanco[1]; Sauvignon blanc[2]	-Low amounts of lees produced since pomace acts as a filter; -Relevant enrichment of aromatic compounds extracted from grape skin.	-Low capacity and speed; -High labour to manually remove the pomace.	[1]Darias-Martín et al., 2004; [2]Catania et al., 2019a; Mondavi, 1965
Horizontal mechanical press (plate press)	Discontinuous, open	Up to 5–6 bars	Not specified	-Relevant extraction of liquid; -Appropriate for large wineries; -Pressure can be applied along the whole length of press drum.	-No pomace filtering action.	Ribéreau-Gayon et al., 2021
Pneumatic press	Discontinuous, open/closed	Up to 2 bars	Catarratto[1]	-Homogeneous and soft pressing; -Temperature, pressure and air contact can be set and monitored; -Immediate extraction of the must.	-Expensive; -Time-consuming; -Lower must extraction in comparison with continuous presses.	[1]Catania et al., 2019b; Del Fresno et al., 2021

processing and more accurate juice extraction methods are applied. In this context, discontinuous pressing is widely used and discontinuous presses have to be upload with grapes and download with pomace. This necessity represents the main drawback of this technology since it takes time (Del Fresno et al., 2021). Discontinuous presses include vertical basket presses, horizontal plate presses and horizontal pneumatic presses (Catania et al., 2019a).

The vertical basket presses (Fig. 3) apply downward or upward pressure. The must is filtered through the solid materials since the skins tend to be collected in parallel to the pressing surface. The grapes are tipped into a preliminary draining section of continuous belt presses, where they proceed to a sandwich compression between two cloths and are gradually flattened between rollers. This method is quick and does not cause any stem tearing (Darias-Martín et al., 2004).

The most used machines for the grape pressing are pneumatic presses (Fig. 4). Pneumatic presses allow a soft and controlled pressing, in which a membrane is filled with compressed air and the highest pressure applied on grapes is about 2 bars (Del Fresno et al., 2021). The process can be set and controlled, but it can take around 3–4 h for completing the pressing cycle. Steps of increasing applied pressure are usually planned; the membrane is deflated, and the must is released between each pressing step. The pneumatic press is a discontinuous closed tank constituted by a stainless-steel cylinder rotating hollow around a horizontal axis, with a side-mounted flexible food grade PVC membrane inside as opposed to a wide wall of longitudinal holed channels that allow must be draining. The crushed destemmed grapes are loaded through a side opening with a sealed door or an axial load valve. After loading, compressed air is used to exert pressure on the other side of the membrane to extract the must. The operation is repeated several times with progressively increasing pressure alternating with a retracted membrane rotation phase to mix the progressively drier marc. Skins and grape seeds are unloaded through the side opening at the end of the extraction phase (Catania et al., 2019b). The pressing with pneumatic press can be carried out limiting or avoiding any contact with air, under inert gas saturation (close press). Another option is the traditional method that includes the oxygen presence during pressing (open press) (Boselli et al., 2010). Horizontal mechanical press represents an older but still widely diffused horizontal press, known as plate press. The compression is carried out by two plates getting closer towards the centre. The horizontal press equipped with a rotating structure allows the mixing of the pomace and, consequently, a major extraction of liquid. It generally applies higher pressure than the pneumatic press as it can work up to 5–6 bars (Ribéreau-Gayon et al., 2021).

Fig. 3. Marmoinier vertical basket press.

Fig. 4. Horizontal pneumatic press.

Each of the presses show some advantages and disadvantages that are summarized in Table 2. Such aspects include the press capacity and fast pressing with high must extraction yield of continuous press leading to higher mechanical constraints on solid parts and high presence of phenolics. On the other hand, the accurate management of pressure possible with the pneumatic press allows a soft pressing and the must fractioning. The accumulation of pomace exerts a filtering action in the case of the basket press, in contrast to the other presses.

4.2. Oxygen exposure

The exposure of oxygen needs attention in particular for the white winemaking. During production of grape juice, oxygen exposure can occur having both a positive and a negative impact on chemical composition, sensory attributes, color and mouthfeel of the resulting wine (Day et al., 2015; Ribéreau-Gayon et al., 2021). Nowadays, the knowledge and oenological technologies can offer to the winemakers various strategies for protecting grapes and musts from undesired oxidative enzymatic processes (Reynolds et al., 2021). During the pressing process, for must addressed to sparkling wine production, to limit the extraction of phenols, whole bunches are pressed (Gawel et al., 2014); the oxygenation of must occurs due to the air present inside the press during the must flowing and pomace crumbling. Moreover, oxygen exposure is also influenced by the press program and deflection frequency leads to increased exposure (Day et al., 2015).

The oxygen plays a role from the beginning of winemaking processes. As soon as grapes are crushed, PPO enzyme is released and it catalyses the oxidation of phenolic substances in the presence of oxygen (Macheix et al., 1991). Nonetheless, the oxygen exposure during pressing can lead to lower concentrations of total polyphenols and catechin (Motta et al., 2014). The oxidation rate is also correlated with acidity, since it decreases at lower pH (Schneider, 1998). The contact with oxygen during pressing exhibits a decisive effect on the content of HCAs and aromas. The moles of oxygen consumed per mole of phenol in white wine is about 5.5 times higher than in red wine. This is mainly due to malvidin derivatives which are present in high concentrations in red wine and they are not directly oxidisable with oxygen (Du Toit et al., 2006). Furthermore, red wine also contains significant amounts of flavanols which are not directly oxidisable with oxygen either. The oxidative reactions can cause the decrease of aroma concentration, occurring especially if must is exposed to oxygen for a long period.

The exposure to oxygen represents the feature for the winemaking approach based on hyperoxidation that can be applied triggering the oxidation instead of avoiding it. This technique involves saturating with oxygen of sulfur-free juice, oxidizing polyphenols, making them precipitate and removing them before the alcoholic fermentation. Lukić and co-authors (2019) investigated the impact of oxygen considering light juice oxidation (LOX) in which juice was purged with oxygen at 18 mg/L and heavy juice oxidation treatment (HOX) in which juice was with oxygen at 90 mg/L. This study showed that oxygen exposure significantly reduced the levels of phenols, especially caftaric and coutaric acids. The effect was more pronounced in HOX, possibly as a result of the oxidation of other phenols, as for example, β-oxidation of ferulic acid to vanillic acid. Even if oxygen is consumed in a short time in grape must, a relevant impact of hyperoxidation can be often negatively correlated with esters, isoamyl alcohol and aroma in general, leading to wines with lower sensory intensity (Lukić et al., 2019).

4.3. Pressing under reductive conditions

The production of white wines under anoxic conditions spread over in the last decades, starting from the production of musts obtained under low occurrence of oxidative reactions (Boselli et al., 2010). The use of inert gases, such as nitrogen, carbon dioxide or argon, minimizes the grape contact with air limiting the oxidative reactions previously described (Catania et al., 2019a).

According to numerous authors, the use of inert gas during pressing ensures a constant draining action with positive results for product quality (Boselli et al., 2010; Motta et al., 2014; Pons et al., 2015). Catania and co-authors (2019a) showed the relevant changes occurring in the composition of Sauvignon blanc must obtained under pressing with nitrogen pressing mode (NP) compared to the traditional air pressing mode (AP). Significant differences were found in the must composition for polyphenols, ashes, readily assimilable nitrogen, titratable acidity, malic acid, potassium being higher in NP samples, while the ethanol, volatile acidity, and carbon dioxide concentration levels were higher in AP samples. Boselli and co-authors (2010) demonstrated that the use of nitrogen gas increased the total phenolic content by 21 % in comparison to air exposed musts. A significant increase of titratable acidity (+29 %) was determined for the must obtained by pressing under nitrogen reaching 6.78 g/L, while the total acidity was 5.27 g/L in the must obtained with air exposure (Catania et al., 2019a). The high level of acidity, higher than 6 g/L, in must create a favorable environment for the development of esters and aromatic compounds in the resulting wine (Catania et al., 2019a). Other authors showed no difference in titratable acidity and malic acid concentration, compared to NP and AP (Pons et al., 2015). The same authors detected GSH up to about 90 mg/L in must produced under nitrogen at low pressure (less than 1 bar). The content of GSH in wine was up to 80–90 mg/L and it was still found after two months of barrels aging. The pressing under nitrogen can represent an interesting strategy for the winemakers aiming to the prevention of GSH loss, a natural antioxidant for must and wine (Pons et al., 2015).

4.4. Temperature

The temperature of the grapes is an important parameter that should be considered during the pressing process. Mafata and collaborators (2018) showed phenol extraction from grapes stored at different temperatures (0, 10, 25 and 30 °C) of must addressed to the production of Méthode Cap Classique wines. These authors found a lower content of phenols in musts and wines obtained from grapes stored at 0 and 10 °C, while higher temperatures (25 and 30 °C) led to musts and wines with higher content of phenols. The opposite trend was observed for sugar levels being higher in must from grapes stored at low temperature. Besides phenols, wines made from grapes stored at higher temperatures had higher color intensity and total hydroxycinnamates content (Gil-Muñoz et al., 1999; Mafata et al., 2018).

A different winemaking technique known as cryoextraction can enhance the extraction of certain compounds. Ruiz-Rodrìguez and co-authors (2020) investigated two different cryoextraction procedures, ultrafast freezing, and liquid nitrogen freezing. Specifically, these authors applied the following winemaking procedures: (i) grapes crushed at room temperature (20 °C) and then pressed (reference wine); (ii) grapes deep-frozen at −28 °C for 15 min, then defrosted for 3 h prior the pressing (UF); (iii) grapes frozen for less than 1 min in liquid nitrogen, defrosted 3 h prior the pressing (LN). Freezing treatments led to wines with a lower titratable acidity and higher alcoholic strength, and more aromatic, as supported by the sensory analysis. Moreover, higher concentrations of terpenes were found in wines produced by frozen grapes. During the cryoextraction, aromatic compounds extraction is facilitated because ice crystals can disorganize the skin tissue and break the pectocellulose. Such modifications of the berry tissues cause the higher extraction of phenols as well, even if the pressing and grinding is carried out at low temperatures (García et al., 2011; Chen et al., 2019).

4.5. Pressing cycle and must fractions

The pressure applied during the pressing affects the final composition of the juice keeping in mind that the must extraction yield is crucial for the wineries to ensure a suitable volumes of wine produced.

The first fraction of juice obtained during the pressing is the free-run juice; it is released during the loading of the press. Although draining cannot replace pressing, a considerable percentage of the juice can be removed purely by gravity due to the weight of grape loaded in the press, which softly creates pressure downwards. Free-run juice contains more dissolved polysaccharides than pressed juices because the frictional forces applied are smaller than those applied by the press. Moreover, it is rich in sugars and tartaric acid since it comes mainly from the intermediate zone of grapes (exocarp and mesocarp) (Reynolds, 2021).

Although the free-run juice is usually less turbid than the first pressed fraction, the accumulation of pomace reduces the turbidity of the subsequent fractions (Darias-Martín et al., 2004). Kerslake et al. (2018) found a decrease of dissolved solids from 5 % (w/v) in the free-run juice to less than 1 % (w/v) in the heavy presses (1.0–2.0 bar) due to the self-filtering of juices can occur in the press due to the presence of pomace (Motta et al., 2014).

Considering the composition of musts collected during the pressing, an increase of pH and the decrease of sugars were found (Darias-Martín et al., 2004). The first must fraction is richer in acids and sugar, while the subsequent fractions are richer in potassium as a consequence of its major extraction from the berry skin. As the pressure increase, the juice is released from central and peripheral parts of the grapes, where the content of sugar is lower. Moreover, pH and potassium concentrations strongly increased within the must when the must extraction yield increases from 55 % to 85% (Aerny et al., 2000).

The extraction of phenolics is also affected by the pressure applied. Ferreira-Lima et al. (2016) reported that light pressing conditions (0.5–1.0 bar) allowed greater extraction of polyphenols without an increase of the browning index. The wines produced with light press must fractions were less susceptible to browning because a major concentration of GSH was found, as well (Darias-Martín et al., 2004; Ferreira-Lima et al., 2016). The presence of GSH can maintain the desired yellow color of white wine and limit the appearance of browning (Hosry et al., 2009). However, the content of GSH was showed to be strongly dependent to the skin contact time leading to its decrease for long skin contact and a relevant increase of GRP, a marker of oxidation occurrence, was found (Maggu et al., 2007). Even if higher pressure led to higher extraction of phenolics, their extraction is affected by their nature: the most easily extracted were hydroxycinnamates and hydroxycinnamoyl tartrates, followed by flavan-3-ols (catechin and epicatechin) (Ferreira-Lima et al., 2016). Among hydroxycinnamoyl tartrates, caftaric acid represents the most likely to be found in white must and its concentration can differ dramatically ranging from 50 mg/L to 250 mg/L in white wines (Du Toit et al., 2006). High concentrations of the caftaric acid make the must more susceptible to oxidation, since it is easily oxidized by PPO enzyme into quinones. A slow increase of pressure can avoid crushing the solid parts of grape limiting the enzymatic activities, especially those responsible for oxidation. In order to prevent the oxidation, sulfur dioxide is commonly added before the pressing. In general, the concentration of antioxidants decreased during pressing due to both the prolonged oxygen exposure and the presence of a high quantity of oxidizable polyphenols in the more heavily pressed juices (Parish-Virtue et al., 2021). Nonetheless, the presence of sulfur dioxide increased polyphenol solubility and extraction from grape skins.

5. The production of sparkling wine

The OIV defined sparkling wines as special wines produced from grapes, musts, or wines processed according to techniques accepted by OIV, with the production of a more or less persistent effervescence resulting from the release of carbon dioxide of exclusively endogenous origin (OIV, 2020a). The sparkling wine production methods can be divided into the traditional (or Champenoise) method and the Martinotti (or Charmat) method. According to the traditional method, the base wine undergoes a re-fermentation in sealed bottles, while the second alcoholic fermentation occurs in autoclave in the Martinotti method (Bordiga et al., 2013).

Pre-fermentative operations cover an even more relevant role for the production of base wines in comparison to still white wines, since the fractioning of must during the pressing cycle is fondamental. This is because wines having varying chemical (e.g., titratable acidity, pH, and phenolic, polysaccharide, and oligosaccharide content) and sensory characteristics (e.g., color, green-grassy note, bitterness, astringency) can result from different must fractions (Bosch-Fusté et al., 2009). Light pressing (around 0.5–1.0 bar of pressure), known as cuvée, usually allows to obtain the best quality juice, while hard pressing (more than 1 bar of pressure), as known as tailles, leads the must fraction not adapted for this winemaking process (Kerslake et al., 2018). The acidity and pH are two relevant parameters monitored and typically taken into account during the pressing in order to accurately performed the must fractioning. High acidity and low pH should be ensured for the production of sparkling wine conferring the desired freshness and ensuring the stability of the wine during the long aging on yeast less (Chidi et al., 2015). The phenolic content of each press fraction should be also taken into account when determining must extraction yield since the excessive extraction of flavonols and hydroxycinnamates negatively affects the taste and color (Gawel et al., 2014). Recently, the spectral phenolic fingerprint determined by UV–Vis was assessed in fractions of must addressed to the sparkling wine production (Kerslake et al., 2018). This method was described as rapid and reliable to describe the phenolic composition, since every phenolic species concentration is detected and quantified at a specific wavelength peak. Taille fractions usually show higher peaks at 280 nm and 320 nm, corresponding to flavonoids and hydroxycinnamates, respectively, than cuvée fractions. For certain sparkling wines, such as Champagne, winemakers usually distinguish juice press fractions based on sensory assessments for phenolic-associated sensations (i.e., perception of drying, coarse in-mouth sensations). To be best of our knowledge, any comprehensive investigation did not provide a detailed description of the entire production chain, from grape to sparkling wine, with specific attention to the pressing stage. The knowledge gap lies in the lack of explanations regarding how the grape characteristics are influenced by the pressing process and then during the vinification for the base wine production and the re-fermentation processes. Investigations will need to cover this knowledge gap for a thorough understanding of the pressing step especially for the sparkling wine production.

6. Further clarification of the grape pressing impact

In the past decades, researches were carried out regarding the pressing and its impact on must and wine quality. Table 3 summarises the main investigated topics and findings as well as the gap of knowledge. These investigations did focus on various pressing conditions, with particular emphasis on the influence of grape skins. Pre-pressing crushing and maceration of the skins showed to increase phenolic extraction (Darias-Martin et al., 2004) and oxidative potential (Maggu et al., 2007). Diverse pressing protocols were employed by Ferreira-Lima et al. (2016) and Dumas et al. (2020), highlighting the impact of high pressure on phenolic extraction and on the depletion of titratable acidity. Additionally, the effect of pressing on aromas was examined by Maggu et al. (2007) and Lukić et al. (2019), emphasizing that higher pressure leads to greater aroma extraction, but also it increases the risk of oxidation. Notably, no screening of aroma and aroma precursors was conducted. In terms of oxidative potential, Lukić et al. (2019) explored pressing under semi-reductive conditions, suggesting that hydroxycinnamates were preserved under anoxic conditions, thereby confirming the findings of Boselli et al. (2010) about phenolic protection. The phenolic fingerprints of must can allow to differentiate different must fractions (Kerslake et al., 2018).

Currently, the primary knowledge gap pertains to the absence of qualitative studies on phenols and aromas under various pressing conditions, as well as their evolution during wine aging.

7. Conclusions

Pressing in one of the pre-fermentative steps relevant for the composition of must. Applying intense pressure and strong constraint on solid parts of grape causes the acidity decrease and the pH increase. In the context of climate change, the acidity loss represents a big concern in particular for the production of sparkling wines. Additionally, pressing

Table 3
Summary of the researches performed on grape pressing.

Refs.	Focus	Major findings	Gap of knowledge
Darias-Martín et al. (2004)	Study the different impact of pressing (i) after crushing and (ii) maceration.	Maceration increased phenols extraction and the free-run must yield, led to a less turbid must.	-Qualitative phenols analysis; -Screening of free aroma and aroma precursors.
Ferreira-Lima et al. (2016)	Investigation of the effect of different pressing conditions on phenolics, antioxidant capacity, and glutathione content.	Heavy pressed must showed higher polyphenol content, radical scavenging power, browning index and glutathione.	-Description of the oxidation trends occurring during storage; -Sensory analysis of wine.
Dumas et al. (2020)	Analysis of the impact of grape juice extraction method.	Acidity was affected by the pressing method, performed under laboratory scale, since different mechanical forces led to variable extraction of potassium.	Industrial-scale experiments.
Maggu et al. (2007)	Study of the effect of skin contact and pressure on the composition of Sauvignon. blanc.	The release of aroma is higher by increasing the pressure which could have a detrimental on the aroma loss due to the increase of the oxidative potential.	Extraction/ depletion ratio of aroma.
Lukić et al. (2019)	Investigaton of the impact of skin disruption and oxygen exposure on phenols, volatiles and sensory characteristics.	The pressing of whole grape bunches under semi-reductive conditions ensured the highest amount of aroma and hydroxycinnamates.	-Other grape varieties should be considered; -Investigation on the suitability of this pressing condition for the production of sparkling wine.
Boselli et al. (2010)	Study of the impact of pressing under anoxic condition on phenolic profile.	About the 20 % more phenolics were preserved by pressing under nitrogen flow.	-Evolution of phenols by means of other technologies despite vacuum and nitrogen applications; -Impact of phenols on sensory characteristics.
Kerslake et al. (2018)	Evaluation of UV–Vis spectral phenolic fingerprint, combined with PCA as a method to discriminate grape juice press fractions.	It was demonstrated to be a suitable method to discriminate between cuvée and taille.	-Real-time discrimination of juice quality; -Combination of qualitative and quantitative determinations; -Evaluation of oxidation degree of the target parameters.

influences the extraction of phenolic, both flavonoid and non-flavonoid species. The presence of the latter can lead to enzymatic oxidation and browning of must. The pressure applied during the pressing influences the presence of the lees in the must contributing to its turbidity and viscosity. These parameters not only affect the must clarity, but could also influence the amount of molecules extracted from solid parts and, consequently, the sensory characteristics and mouthfeel of the resulting wine. Beside the pressure applied, the must composition is affected by the operating conditions including the equipment used, the oxygen exposure or the reductive conditions, the temperature of grape. Other characteristics of grapes, including berry composition, berry hardness, skin/pulp ratio and berry point of break are crucial and should be taken into account when setting the pressing. The accurate management of pressing, based on the specific grape, and must fractioning allows to obtained the must which composition will address a desired wine style.

This review lacks in certain aspects related to both the equipment and pressing conditions. Specifically, the accurate comparison of the different pressing equipment applied on the grape harvested from the same vineyard was not studied, yet. Similarly, different pressing conditions in terms of pressure, oxygen exposure, temperature were investigated in few researches. As a consequence, the influence of the grape varieties by applying the same pressing conditions could not be reviewed. Additionally, the relation potentially existing between the grape composition and must composition depending on the pressing applied could not be discussed since this data is not available. Finally, the interaction between different pressing methods and the final characteristics of still and/or sparkling wine could not be fully explained by the studies examined.

Further investigations will need to qualitatively analyse the extracted phenolic compounds in order to have a deep comprehension of this relevant winemaking step. Moreover, the quantitative and qualitative extraction of aroma and their precursors will require additional studies. The optimization of the pressing is a challenge for the winemakers that should be done for specific grape harvested in a specific vintage. Such aspect will allow to limit the addition of antioxidant and the correction for a winemaking approach with minimal intervention supporting the implementation of sustainable wine industry.

Author statement

The authors declare that they have no financial and personal relationships with other people or organizations that can inappropriately influence their work.

Ethical statement - studies in humans and animals

I declare the paper "Exploring grape pressing for sparkling wine production: a comprehensive literature review on physicochemical parameters and technological applications" does not involved human subjects and/or animals.

CRediT authorship contribution statement

Gvantsa Shanshiashvili: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Data curation. **Marta Baviera:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Data curation. **Daniela Fracassetti:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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