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ORIGINAL RESEARCH ARTICLE

Influence of vintage and grape maturity on volatile composition and foaming properties of sparkling wine made from Savvatiano (*Vitis vinifera* L.) variety

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ABSTRACT

The timing of grape harvest is critical in the winemaking process of sparkling wines. It is essential for grapes to have the right amount of sugars and the optimum amount of sugars and level of acidity perfect level of acidity as they ripen. This is crucial not just for achieving the desired alcohol content in the wine but also for ensuring the production of the aromatic precursors. The chemical composition of sparkling wines is closely linked to the quality of their foam. The goal of this study was to determine how different levels of grape maturity impact the chemical and sensory properties of Savvatiano sparkling wines after 15 months maturation in the bottle. Grape ripening stage was found to have a significant influence on the content, composition and development of organic acids and volatile compounds in the wine, and on its sensorial attributes. In the resulting Savvatiano sparkling wines produced by a single grape variety, those produced from grapes at the earliest stage of maturity exhibited higher levels of terpenes, organic acids and foam characteristics. This was reflected in the sensory evaluation, these wines scoring the highest for descriptors like "floral", "green apple" and "foam intensity". This study represents the first analysis of the chemical composition and sensory traits of white sparkling wine made from the indigenous grape variety Savvatiano. By applying a comprehensive approach that examines both wine metabolites and sensory attributes, it is possible to determine the ideal harvest time for producing high quality Savvatiano sparkling wines.

KEYWORDS: sparkling wine, Savvatiano, foam, volatile compounds, sensory profile, grape berry maturity, base wine

INTRODUCTION

Savvatiano (or Savatiano*) is the most widespread white grape variety in Greece, being cultivated in a total area of 11,000 ha. (Hellenic Statistical Authority, 2022). It is a native variety of the Greek region Attica that has been associated with retsina production since ancient times. It is systematically cultivated in central Greece, and a lower percentage is also produced in Western Peloponnese. Moderately vigorous and highly productive, this variety has the ability to adapt to various environments of different soil types (dry, poor, gravelly and calcareous soils) and climate, important factors in the production of high-quality products (van Leeuwen & Seguin, 2006). Savvatiano is a neutral variety used to produce wines with weaker to more neutral flavours and aromas (Miliordos *et al.*, 2022) in comparison with other Greek indigenous grapevine varieties (Nanou *et al.*, 2020). Consequently, in the Greek market it is not classified as a nobble variety. However, in recent years, the adaptation of modern viticulture and winemaking techniques has improved the profile of the wines of the variety, with dry white wines that have balanced acidity, citrus, tropical and banana aromas, rich body, great aftertaste, and which age well, developing earthy aromas and a mineral undertones (Miliordos *et al.*, 2022). This demonstrates that Savvatiano is a versatile and multifaceted variety, warranting research into its suitability for producing other types of wines, such as sparkling wines.

The global consumption of sparkling wines has increased significantly in recent decades, increasing by 57 % since 2002 (OIV FOCUS, 2022), and the annual growth rate (compound annual growth rate–CAGR) is expected to increase by 7.43 % by 2027 (www.statista.com). In Greece, the sparkling wine market is small, but important experimental work has been carried out by wineries and research groups of developing more sparkling wines.

The quality of a sparkling wine is mainly defined by its foam (Culbert *et al.*, 2017; Esteruelas *et al.*, 2015). The ability of a sparkling wine to form stable and persistent foam is evaluated positively by consumers. Due to the importance of foam in sparkling wines, several researchers have studied the factors that affect its characteristics (Andrés-Lacueva *et al.*, 1996; Brissonnet & Maujean, 1993; Kemp *et al.*, 2017; Vanrell *et al.*, 2007). It has been shown that foam quality depends on sparkling wine chemical composition, which is in turn influenced by the grape variety, level of maturity of the grapes and vinification conditions (Esteruelas *et al.*, 2015; López-Barajas *et al.*, 1997; López-Barajas *et al.*, 1998). A number of factors contribute to the stabilisation of the surface of the bubbles that form the foam, with the hydrophobic part of the surface facing inward (gas phase) and the hydrophilic part facing the aqueous phase. Several active foaming substances seem to play a significant role due to their physicochemical properties. The effect of ethanol, organic acids, lipids, proteins, polysaccharides, aging in bottles (mainly the effect of autolysis of mannoproteins), as well as the infection of grapes by *Botrytis cinerea* have been studied (Esteruelas *et al.*, 2015; Kemp *et al.*, 2019).

Other important aspects of sparkling wines are aroma and flavour. Aroma and flavour not only depend on the volatile compounds present in the wine but are also the result of synergistic effects caused by the simultaneous action of many classes of compounds present at various concentrations in sparkling wines (Souza *et al.*, 2022). In addition to the most common factors, such as climate, soil, cultivar, grape maturity, pH and temperature, aroma can also be influenced by aging with lees contact, fermentation in the bottle and/or the autolysis of yeast (Alexandre & Guilloux-Benatier, 2006). Studies of wine volatile compounds over the past ten years have mostly focused on establishing correlations between the changes in their concentrations and include both the second fermentation and the time of lees contact (Torrens *et al.*, 2008; Pozo-Bayón *et al.*, 2010; Welke *et al.*, 2014).

In this context, the aim of the present research work was to examine the influence of maturity level on the chemical and sensory properties of sparkling wines from the Savvatiano grape variety during two consecutive vintages (2019–2020).

MATERIALS AND METHODS

1. Grape sampling

The experiment was carried out during two consecutive vintages (2019 and 2020) on grapes from a commercial vineyard planted with the *Vitis vinifera* L. Savvatiano in the Valley of the Muses (Askri, Viotia; 38° 19′ 30″ N, 23° 05′ 37″ E, at an elevation of 450 m) in Central Greece. The vines were more than 60 years old and pruned as bush vines. The vineyard was situated on a deep loamy soil and was managed according to standard agronomical practices of the region and without irrigation. Grapes were harvested at three maturity levels based on the soluble solid content of the grape juice. The first harvest took place when total soluble solid content was between 15.5 ± 1 °Brix, the second at 17.5 ± 1 °Brix and the third at 20.0 ± 1 °Brix. Around 220 kg of grape bunches was harvested early in the morning and randomly from a block of 10 rows x 20 vines from the central part of the vineyard. The grapes were transported to the experimental winery of the laboratory of enology and alcoholic drinks of the Agricultural University of Athens in 20 kg grape picking crates, and were stored in a cool room at 5 °C for 24 h.

2. Base wine production

Grapes from each harvest were separated into three batches and were destemmed and pressed gently with a water bladder wine press to obtain around 0.60-0.65 L of free run grape juice per kg of grape. The obtained grape juice was immediately sulfited with 30 mg/L SO_2, and pectinolyctic enzymes (0.02 g/L, Safizym Clar, Fermentis, France) were added to increase clarification. After the settling of the grape juice for 24 h at 4 °C, 40 L of clean grape must from each of the three replicates was racked to 50 L fermentation tanks and inoculated with 200 mg/L *Saccharomyces cerevisiae*

(Vivace, Renaissance Yeast, Canada), according to the manufacturer's instructions. Fermentations were conducted in controlled temperature conditions at 16 ± 1 °C. The base wines were then cold stabilised and metabisulfite was added (30 mg/L SO_2). In order to avoid stuck or sluggish fermentations, nitrogenous nutrition was added in two doses and in two different forms. A few hours after inoculation (3-5 h), organic nitrogen was added in the form of autolysed yeast cells at a concentration equal to that of the yeast, 200 mg/L (SpringFerm™, Fermentis, France), in order to enrich the must in amino acids, sterols, minerals and vitamins. The second addition of nitrogen in the form of diammonium phosphate (DAP), 200 mg/L (SpringFerm™ Equilibre, Fermentis, France) took place when 1/3 of sugars was consumed by the yeast. Alcoholic fermentation showed a regular trend and was considered finished when the reducing sugar concentration was lower than 2 g/L. At the end of fermentation (approximately after 10 days), the wines were racked in airtight inox tanks.

3. Sparkling wine production

All the produced base wines (3 replicates from 3 maturity levels; *i.e.*, a total of 9 wines) were used to produce sparkling wines via the traditional method (*champenoise*). Base wines were supplemented with 22 g/L of sucrose (common white table sugar), 60 mg/L bentonite to improve the riddling (Bentonite Premium, Dolmar Spain), and 250 mg/L organic nitrogen (SpringFerm™). 250 mg/L of *Saccharomyces bayanus* (Vivace, Renaissance Yeast, Canada) yeast was pre-activated and adapted before adding them with the supplemented wine to the 750 mL sparkling wine bottles. The bottles were sealed with bidule and crown caps. Fifteen months later, all the sparkling wines were disgorged and analysed. Three biological replicates of each sparkling wine and of each of the three replicates of every maturity level were analysed.

4. Physicochemical analysis of musts and wines

Following the International Organization of Vine and Wine methods (OIV, 2023), the grape juice was analysed for total soluble solids and total acidity, and the base and sparkling wines were analysed for total acidity, pH, volatile acidity, residual sugar and alcohol content. Colour intensity (CI), browning and total polyphenol index (TPI) were measured according to Ribéreau-Gayon *et al.* (2006). The colour intensity was estimated as the sum of absorbance at 420 nm, and the browning as the absorbance at 420 nm. The samples were centrifuged (10000 rpm for 10 min) before being analysed using a 10 mm-length quartz cuvettes. Spectrophotometric measurements were performed using a Shimadzu UV-1900 double-beam spectrophotometer (Shimadzu Scientific Instruments Inc., Kyoto, Japan). The total phenolic index (TPI) was determined by diluting the sample 20 times and measuring the absorbance at 280 nm. The CIELAB coordinates, lightness (L*), chroma (C*), hue (h*), red-greenness (a*) and yellow-blueness (b*) were determined according to Ayala *et al.* (1997), and the data were processed using MSCV software (Ayala *et al.*, 2001). Three biological samples of grape juice, base and sparkling wines were used for each maturity level and replicate.

5. Measurement of sparkling wine foam parameters

The foam properties of the sparkling wines were analysed following the Mosalux protocol (Maujean *et al.*, 1990). Wines were degassed by centrifugation (12000 × g per 10 min) and stored at stable temperature (18 °C) for 24 h. A graduated glass cylinder with a porous glass bottom and a CO_2 entrance was filled with 100 mL of the sparkling wine sample. Carbon dioxide was supplied from a CO_2 gas bottle at a constant pressure (2 bar) and passed through the porous glass into the wine in a constant flow (115 mL/min). The graduated cylinder served to measure the maximum height (HM) reached by the foam of the wine sample with the application of the CO_2. HM expresses the foaming ability of the wine. The other parameter measured was the stable height (HS) reached after CO_2 injection, which expresses the ability of the wine to produce stable foam via the persistence of the foam collar. All analyses were performed in triplicate.

6. Organic acids and glycerol determination by high performance liquid chromatography

Sparkling wine organic acids (tartaric, malic, citric, succinic, lactic and acetic acid) and glycerol were determined by means of a Shimadzu HPLC system, model LC-20 (Shimadzu Scientific Instruments Inc., Kyoto, Japan), equipped with a quaternary solvent pump (LC 20AT model), degasser (DGU 20A model), thermostatted column compartment (CTO 20AC model), and autosampler (SIL 20 AC model) coupled to a diode array detector (DAD) (SPD-M20A model) and a refractive index detector (RID) (Shimadzu RID-10A). Data were obtained and processed using Lab Solutions Multi LC Software (Shimadzu).

The analytical method used was based on that of Coelho *et al.* (2018). Briefly, an ion exchange resin column, Agilent Hi-Plex (H+ model, 300 mm x 7.7 mm, and 8 µm particle size) (Agilent Technologies, CA, USA), was fitted with a 5 mm x 3 mm Hi-Plex pre-column, (Agilent Technologies). Wine samples were centrifuged at 12000 rpm for 10 min and filtered through a 0.20 µm syringe filter. A volume of 10 µL of the filtered samples was injected. The temperature of the column compartment was maintained at 70 °C, and the RID flow cell at 50 °C. The flow rate applied was 0.5 mL/min, with a run time of 20 min. The mobile phase was 4.0 mM of H_2SO_4 in ultrapure water. For the determination of organic acids, detection was conducted in the DAD at 210 nm, while for the glycerol, RID was used. The studied compounds were identified based on the retention time of the external standards, and the quantification of each compound was accomplished using calibration curves based on the peak areas of the standards.

2.7. Quantitative determination of volatile compounds

Volatile compounds were analysed in the sparkling wines after 15 months of maturation following an adaptation of

the analytical procedure described by Ivanova *et al.* (2012) for white wine samples. The volatile compounds of interest were isolated following a liquid-liquid extraction protocol. Forty mL of wine was spiked with the 3 internal standards 3-octanol, ethyl heptanoate and heptanoic acid, so that their final concentration in the wine was 10 mg/L for each of them. The spiked sample was placed in a glass-capped Erlenmeyer flask and a volume of 5 mL of dichloromethane was added; this was followed by continuous stirring for 15 min using a magnetic stirrer. The mixture was then centrifuged at 4000 rpm for 10 min at a temperature of 4 °C. Once the phases had separated, the dichloromethane layer was collected and the extraction process was repeated. Afterwards, the vial containing the total organic phase was evaporated under a nitrogen stream to a volume of approximately 500 µL of extract, and then a volume of 1 µL was injected into the GC-MS system. All extractions were performed in triplicate. The analysis of the volatile compounds in the wine samples was performed using a Perkin Elmer Clarus SQ8S mass spectrometer coupled to a Perkin Elmer Clarus 590 gas chromatograph (Perkin Elmer,Waltham, MA, USA). The polar capillary column used for the separation of the compounds was a DB-WAX type from Agilent (ID: 0.20 mm, film thickness: 0.20 m, and length: 50 m). The working parameters were as follows: injector temperature of 250 °C, MS source of 250 °C, and impact energy of 70 eV operating in EI mode. The initial temperature was 40 °C for 2 min, which was then increased to 240 °C at a rate of 5 °C/min. The carrier gas was He at a flow rate of 1.0 mL/min. Samples were injected in split/splitless mode. A mass range of 40–400 m/z was acquired at one scan per second. A quantitative analysis and identification using commercial standards and external calibration curves was performed.

2.8. Sensorial analysis

The sensory evaluation of the wines was carried out by a panel of 12 experienced panelists (age range of 25 to 55 years, six women and six men) in the tasting room of the Laboratory of Enology and Alcoholic Drinks of the Agricultural University of Athens. All the panelists had given their informed consent to taking part in the study. The panelists were trained according to Nanou *et al.* (2020) and were instructed to refrain from utilising perfumes or any form of perfumed cosmetic products that could potentially influence their sensory evaluations. These comprehensive training sessions ook place over three weeks, during which the panelists engaged in a variety of structured activities aiming to enhance their olfactory skills. The training sessions involved the systematic smelling of established odour reference standards as well as the detailed description of the various odours present in different types of wines. Specifically, panelists were exposed to aroma reference standards sourced from an aroma box (manufactured by Pulltex, located in Barcelona, Spain), which served the crucial purpose of enabling them to become well-acquainted with the diverse range of odours that can typically be detected in wine.

The wines (20 mL/tasting glass) were served at 8–10 °C in standard wine-tasting glasses (ISO 3591, 1977). The wine judges attended two training sessions. In the first session, the panelists were trained using appropriate standard solutions and then were served samples for assessment. The evaluation of the wine samples (two replicates of three wines: *i.e.*, six samples in total) was divided into two sessions over a period of one week. Each session was conducted in individual booths under white light. Each sparkling wine was opened immediately prior to pouring, and only when the judges were already seated in the evaluation booths. The samples were presented with 3-digit blinding codes in a monadic sequence and following a Latin Square Design. The perceived intensity of each attribute was assessed using a 1–5 scale (0: null; 5: very strong).

2.9. Statistical analysis

All the values are shown as the mean and standard deviation. Statistical analyses were performed using Statgraphics Centurion application (version 1.0.1.C). The significance of the results was determined by carrying out an unpaired t-test or one-way ANOVA with Tukey's test. A multivariate statistical data analysis (MVA) of the samples was performed with XLstat (XLSTAT 2017: Data Analysis and Statistical Solution for Microsoft Excel; Addinsoft, Paris, France, 2017). The sensory evaluation data were analysed via a non-parametric Kruskal Wallis one-way analysis of variance using Statgraphics Centrurion. When the p-values were < 0.05, a *Post-Hoc* Mann–Whitney–Wilcoxon Test was applied to compare, one by one, the wines for each variable.

RESULTS

1. Harvest dates and physiochemical parameters of the grape berries

The effect of the different harvest dates on the Savvatiano must physiochemical parameters was investigated. Grapes were harvested at three different maturity levels determined by measuring the grape berry total soluble solids (TSS), total acidity and pH (Table 1). In both vintages (2019 and 2020), TSS levels were significantly lower at the first grape maturity level, with a difference of approximately 2.5 °Brix in comparison to the second maturity level and a difference of 2.5 °Brix between the second and third levels (Table 1). Similarly, pH increased between the first and second maturity levels and remained stable at the third maturity level in the first year; meanwhile in the second year the pH was similar at the first two maturity levels and increased at the third. On the other hand, titratable acidity was significantly higher at the first maturity level than at the second and third. Hence, this confirms that the grapes were harvested at different maturity levels.

2. Base and sparkling wines physicochemical parameters

Table 2 shows the conventional analysis of base and sparkling wines of the Savvatiano variety at the three different maturity levels in the two consecutive years of the experiment. In terms of alcoholic strength a statistically significant difference was found between the wines from grapes of different maturity

TABLE 1. General parameters of Savvatiano grape juices.

	Maturity level	Harvest dates	TSS (°Brix)	pH	Total acidity (Tart. Ac. g/L)
2019	1st	16/09/2019	14.9±0.05c	2.81±0.02b	5.42±0.11a
	2nd	29/09/2019	17.5±0.09b	3.31±0.01a	4.44±0.01b
	3rd	10/10/2019	20.1±0.05a	3.30±0.01a	4.00±0.04c
2020	1st	02/09/2020	16.6±0.03c	3.26±0.14b	5.47±0.09a
	2nd	15/09/2020	17.7±0.02b	3.29±0.05b	4.72±0.10b
	3rd	02/10/2020	20.5±0.08a	3.43±0.03a	3.91±0.04c

Different Latin letters indicate statistically significant differences between different maturity levels of the same year (Tuckey's HSD test, $p < 0.05$).

TABLE 2. General parameters of base and sparkling wines.

		Base wine		Sparkling wine	
	Maturity level	2019	2020	2019	2020
Alcohol title (% v/v)	1st	9.20±0.05c	10.0±0.04a	10.7±0.18a	11.2±0.20a
	2nd	10.7±0.07b	11.3±0.06b	12.1±0.04b	12.5±0.01b
	3rd	12.3±0.09a	12.5±0.09c	13.5±0.06c	13.4±0.07c
Total acidity (g/L)	1st	7.10±0.19a	6.88±0.10a	6.68±0.08a	6.43±0.15a
	2nd	5.45±0.07b	5.21±0.10b	5.22±0.10b	5.70±0.26b
	3rd	5.10±0.07c	4.91±0.08c	4.71±0.17c	4.77±0.21c
pH	1st	3.07±0.01a	3.10±0.01a	3.12±0.03b	3.21±0.01c
	2nd	3.36±0.01c	3.18±0.03b	3.39±0.05b	3.27±0.01b
	3rd	3.28±0.01b	3.31±0.01c	3.37±0.01a	3.37±0.01a
Volatile acidity (g/L)	1st	0.20±0.06a	0.31±0.03a	0.22±0.02a	0.24±0.02a
	2nd	0.21±0.01a	0.11±0.01a	0.32±0.02b	0.39±0.03b
	3rd	0.19±0.01a	0.15±0.01a	0.48±0.02c	0.49±0.01c
Residual sugars (g/L)	1st	1.10±0.04a	0.52±0.03b	0.45±0.10a	0.25±0.01a
	2nd	0.96±0.01b	0.75±0.04a	1.09±0.97b	0.19±0.01b
	3rd	0.87±0.02c	0.81±0.03a	1.46±0.76b	0.42±0.06c

Different Latin letters indicate statistically significant differences between different maturity levels of the same year (Tuckey's HSD test, $p < 0.05$).

levels in the same year for both base and sparkling wines. The greater the grape maturity, the higher the ethanol content of the produced base wines. The ethanol levels for each maturity level were within the limits determined during the experimental design and were considered desirable for the conduct of the experiment, with a difference in alcohol strength between the three maturity level of 1.2-1.5 alcoholic degrees per maturity level. Similarly, the alcoholic degree of the sparkling wines was higher at the highest maturity level, with almost the same differences between the maturity levels as for the base wines. The increase in alcohol content from base wines to sparkling wines was similar in all the wines (1.1-1.5 % v/v), indicating a slight deviation in the yield of the second fermentation in the bottles. This increase corresponds to the transformation of the added sugar (22 g/L) in the second fermentation. Moreover, total acidity decreased with statistically significant differences between maturity levels for both years for base and sparkling wines, while the pH increased during ripening.

In all the base wines, volatile acidity was quite low and increased in the sparkling wines of the second and mainly third ripening stage, albeit at acceptable levels. This may be due to the higher level of ethanol content. In addition, the data from the base wines show that the fermentations were completed successfully, as the residual sugar levels were at the appropriate levels for dry wines (Table 2). Likewise, in the case of sparkling wines, the sugar content indicated that the second alcoholic fermentation in the bottle had also been completed successfully and that, in all cases, the yeast had metabolised glucose and fructose to produce ethanol. "Liqueur de dosage" was not added in order to be able to study the characteristics of the sparkling wines after the disgorge; therefore, the sugar content of the sparkling wines was only due to the remaining sugar after the second fermentation.

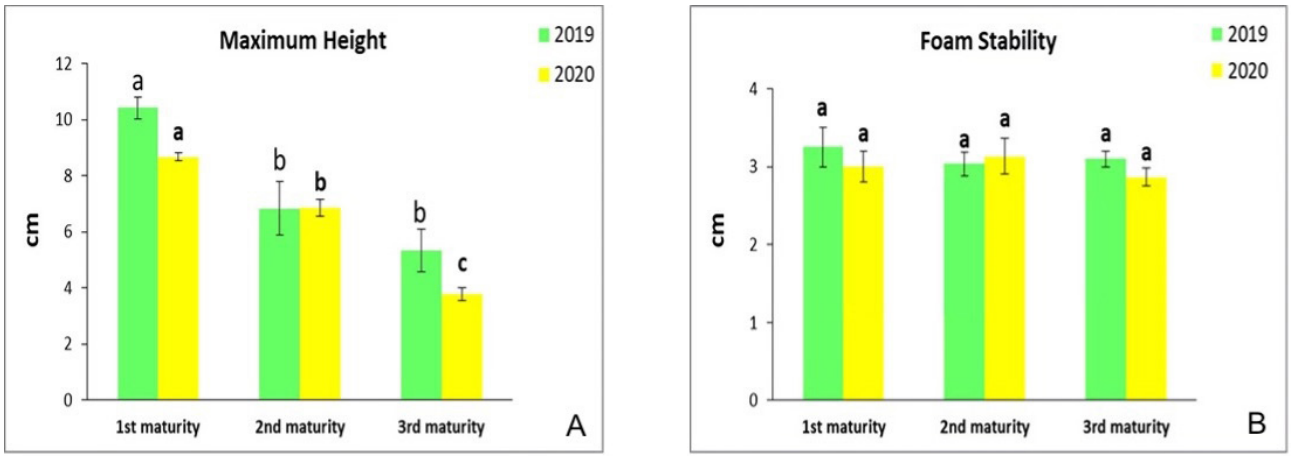


FIGURE 1. A) Maximum height reached by the foam after CO_2 injection through the glass frit, which represents the wine's foaming ability. B) Stable height during CO_2 injection, which represents foam stability. Different Latin letters indicate statistically significant differences between different maturity levels of the same year (Tuckey's HSD test, $p < 0.05$).

3. Foaming properties

The foaming properties of the sparkling wines after 15 months of maturation in bottles were measured using an adapted version of the Mosalux (Maujean *et al*, 1990; Poinsaut, 1991). The maximum height of the foam was found to be clearly linked to maturitu level (Figure 1A), being recorded in both vintages of the sparkling wines at the first maturity level and thereafter decreasing with maturity level (Figure 1A). Concerning the 2020 vintage, the foam heights were lower at the first and third maturity levels than in the 2019 vintage. This may be due to the increased ethanol content negatively affecting the foam (Dussaud *et al.*, 1994). These findings are in line with those of Esteruelas *et al.* (2015), who compared different varietal sparkling wines at two different maturity levels in two vintages. Regarding the height at which the foam stabilised, it remained the same for all the wines at the different maturity levels in both years. Moreover, no differences were observed between the two years in terms of foam stability (Figure 1B). Therefore, foam stability was unaffected by both grape ripeness and the winemaking process that turns base wine into sparkling wine (Esteruelas *et al.*, 2015).

4. Determination of volatile composition

The GC-MS analysis of the sparkling wine samples enabled quantification of 19 volatile compounds belonging to the chemical classes of alcohols, esters, acids, acetates and terpenes. A significant variation in terms of volatile concentrations was observed, and a one-way ANOVA was carried out for each volatile compound, using maturity stage as a factor. The concentrations of the individual compounds and their total concentrations in volatile compound groups (Total alcohols, Total ethyl esters, Total acids, Total acetates and Total terpenes) are shown in Figure 2, as well as Tables S1 and S2.

Higher alcohols are derived from the metabolism of sugars or from the catabolism of amino acids by yeasts (Waterhouse *et al.*, 2016). 2-methyl-1-propanol and isoamyl alcohol were the compounds present in the highest concentrations in the sparkling the major compounds found in the sparkling wines (Tables S1 and S2). Quantitatively, the main alcohols found in the wines and their associated aromas were: 2-methyl-1-propanol (burnt aromas), 2-phenylethanol (characteristic honey and rose aroma), isoamyl alcohol (solvent aromas) and methionol (boiled potato aroma). Meanwhile, it is noteworthy that various other chemical compounds tend to exist within the environment in concentrations that fall significantly below the threshold of human perception, rendering them largely unnoticed and unrecognized by individuals. In contrast to methionol, which is an exception to this observation, all of the other compounds in question were detected at concentrations that exceeded their established thresholds of perception, thereby making them more readily identifiable and discernible within the sensory framework. Isoamyl alcohol and 2-phenylethanol tended to increase in concentration with maturity level for 2019, whereas there is no clear trend for the 2020 vintage (Table S1). The total concentration of the alcohols varied between 230 and 325 mg/L. At concentrations below 400 mg/L they contribute positively to the wine's aroma, imparting complexity to all wines (Rapp & Mandery, 1986). In the present study, the concentrations of the alcohols tended to increase for the 2019 vintage, without the differences being statistically significant (Figure 2).

Ethyl esters are known to contribute to flower and ripe fruit aromas (Zhang *et al.*, 2013). In wines, the majority of ethyl esters are secondary or tertiary aroma compounds that are absent from grapes and are formed during fermentation and aging. The most important groups of esters in wine are ethyl esters and acetic acid esters, whose production is influenced by variables such as individual amino acid concentrations, type of yeast employed, temperature, aeration during fermentation and must sugar concentration. Various research groups have detected the presence of ethyl esters in sparkling wines (Di Gianvito *et al.*, 2018; Tufariello *et al.*, 2021). Here, among the ethyl esters, ethyl octanoate, ethyl hexanoate,

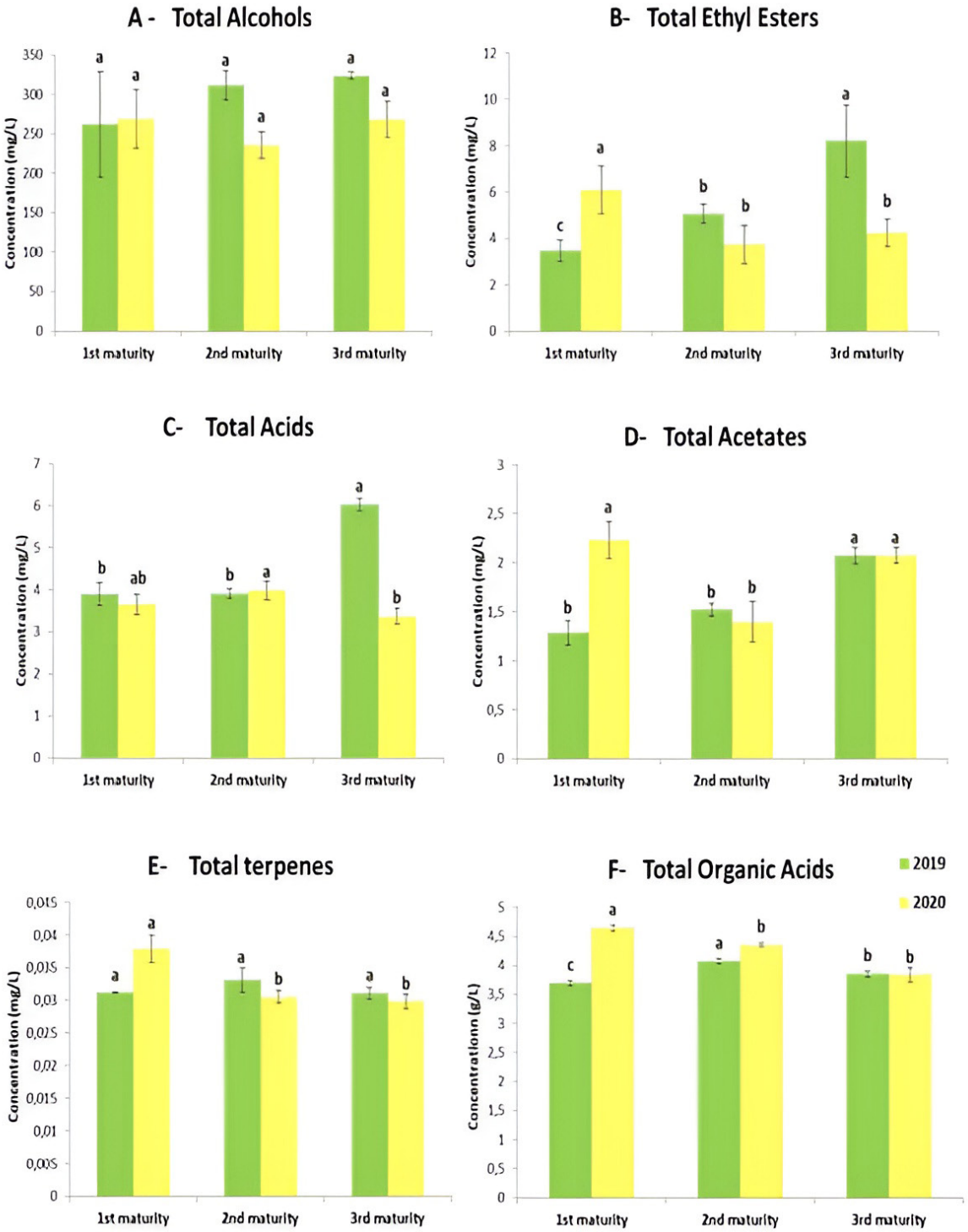


FIGURE 2. Total concentrations of alcohols (A), ethyl estesr (B), acids (C), acetates (D), terpenes (E) and arganic acids (F) of the sparkling wines of the Savvatiano variety from the 2019 and 2020 growing seasons. Different Latin letters indicate statistically significant differences between different maturity levels of the same year (Tuckey's HSD test, $p < 0.05$).

ethyl decanoate, ethyl butyrate, ethyl 2-methyl-butyrate and ethyl 3-methylbutyrate were determined (Table S1 and S2), while among the acetates, isoamyl acetate, 2-phenethyl acetate and hexyl acetate were determined (Table S1 and S2). For the 2019 vintage, the concentrations of almost all the compounds increased from the lowest maturity to the highest, in contrast to the 2020 vintage, for which the concentrations did not show any fixed pattern (Figure 2). In the 2019 vintage, the total concentrations of ethyl esters and acetates tended to be the highest in the sparkling wines of the third maturity level and the lowest in those of the first maturity level (Figure 2). Regarding these compounds, contradictory data have been recorded by different research groups: in particular, Martínez-García *et al.* (2017) found ethyl esters to decrease in Macabeo-Chardonnay-based (60:40) sparkling wines, whereas Welke *et al.* (2014) observed increased

TABLE 3. Total phenolic index and colour parameters.

		Base wine	
	Maturity level	2019	2020
Total phenolic index	1st	6.13±0.04c	9.23±0.20a
	2nd	7.19±0.10b	8.16±0.05b
	3rd	11.53±0.55a	9.08±0.09a
A420	1st	0.061±0.004b	0.071±0.005a
	2nd	0.094±0.012a	0.059±0.005b
	3rd	0.102±0.001a	0.076±0.001a
*L**	1st	99.00±0.26a	98.73±0.29a
	2nd	98.07±0.65b	98.93±0.06a
	3rd	98.27±0.06ab	98.90±0.01a
*C**	1st	4.27±0.06c	5.20±0.20b
	2nd	6.15±0.75b	4.44±0.08a
	3rd	7.02±0.04a	5.45±0.08a
*h**	1st	99.16±1.34a	97.70±0.96b
	2nd	96.29±1.14b	97.86±0.66b
	3rd	96.85±0.40b	98.63±0.16a
*a**	1st	-0.68±0.09a	-0.69±0.07a
	2nd	-0.66±0.06a	-0.61±0.06a
	3rd	-0.84±0.04b	-0.82±0.03b
*b**	1st	4.22±0.08b	5.16±0.21a
	2nd	6.11±0.76a	4.40±0.08b
	3rd	6.98±0.05a	5.39±0.08a

Different Latin letters indicate statistically significant differences between different maturity levels of the same year (Tuckey's HSD test, $p < 0.05$).

concentrations in their Chardonnay-based sparkling wines. For 2020 in the present study, the concentration of ethyl esters decreased with maturity level, and a similar trend was found for total acetates (Figure 2). Esters tend to decrease after the second fermentation and during ageing due to the release of enzymes, such as esterases, which are involved in their breakdown in the adsorption of these compounds on the lees, or as a result of their thermodynamic instability; however, they can also be created in parallel by higher alcohols (Ruiz-Moreno *et al.*, 2017; Ubeda *et al.*, 2019).

The metabolism of yeasts and bacteria produces short- (< 6 carbons), medium- (6 to 12 carbons) and long-chain (> 12 carbons) fatty acids, the first two categories being the main volatile fatty acids (Ruiz *et al.*, 2019). The short chain fatty acids are butyric, propanoic, isobutyric and isovaleric, and they are characterised by cheesy aromas. Tables S2 and S3 list the concentrations of isovaleric acid, butyric acid, isobutyric acid and hexanoic acid found in this study. For 2019, there is an increase in the concentrations of isovaleric acid, butyric acid and hexanoic acid with maturation after remaining in the bottles for 15 months, which was not the case for isobutyric acid (Table S1). For 2020, an increase in isovaleric acid and a decrease in hexanoic acid were observed with maturation (Table S2). Regarding isobutyric and butyric acid, similar levels were recorded. In terms of total concentration, only the third maturity level of the first year showed an increased concentration compared to the rest of the sparkling wines (Figure 2).

Terpenes come from the grape and are of particular interest as they are characterised by a low perception threshold and contribute to the aroma of wines by imparting fruit and flower aromas (Carrau *et al.*, 2008). The monoterpenes linalool, geraniol and nerol are particularly responsible for the characteristic floral aroma of grapes and wines (Darriet *et al.*, 2012). Linalool and nerol were detected in the sparkling wines (Table S1 and S2). Their concentrations are similar in both years and in all the different samples, except in the case of linalool in the second year, which decreased in concentration in the samples from the higher maturity stages (Table S1 and S2). The increased levels of linalool with maturity stage can also contribute favorably to wine aroma with a pleasant lemon aroma (Darriet *et al.*, 2012). A similar pattern was observed for total terpenes, which showed similar concentrations in all the samples in the first year, and a tendency to decrease with maturity in the second year (Figure 2).

TABLE 4. Organic acids and glycerol.

		Base wine	
	Maturity level	2019	2020
Tartaric acid	1st	2.01±0.01a	2.00±0.01b
	2nd	1.89±0.03b	2.04±0.01a
	3rd	1.23±0.01c	1.46±0.01c
Malic acid	1st	0.63±0.02a	1.00±0.01a
	2nd	0.42±0.02b	0.60±0.03b
	3rd	0.30±0.02c	0.34±0.01c
Citric acid	1st	041±0.02b	0.41±0.01c
	2nd	0.48±0.01a	0.49±0.01b
	3rd	0.43±0.02b	0.56±0.02a
Succinic acid	1st	0.38±0.07c	1.09±0.05b
	2nd	0.96±0.07b	0.91±0.01c
	3rd	1.55±0.01a	1.23±0.07a
Lactic acid	1st	0.04±0.01a	0.02±0.01a
	2nd	0.05±0.01a	0.02±0.01a
	3rd	0.02±0.01b	0.02±0.01a
Acetic acid	1st	0.21±0.01c	0.12±0.01b
	2nd	0.28±0.01b	0.29±0.02a
	3rd	0.33±0.01a	0.24±0.03a
Total organic acids	1st	3.69±0.05c	4.65±0.06a
	2nd	4.07±0.05a	4.35±0.04b
	3rd	3.85±0.05b	3.83±0.12c
Glycerol	1st	6.50±0.18a	6.22±0.04a
	2nd	7.92±0.06b	6.64±0.04b
	3rd	8.05±0.18b	9.14±0.09c

Different Latin letters indicate statistically significant differences between different maturity levels of the same year (Tuckey's HSD test, $p < 0.05$).

5. Total phenolic index and colour parameters

In the 2019 vintage, TPI was observed to increase with grape maturity. Meanwhile, in 2020, TPI decreased slightly in the sparkling wine at the second maturity level, but increased at the third maturity level, regaining the values of the first maturity level (Table 3).

Table 3 also shows the colour intensity of the wines and the CIELab coordinates. According to the photometrical analysis, the wine colour intensity (expressed as absorbance at 420 nm) was low. There is an increase in absorbance from the first to second maturity of the sparkling wine for the 2019 vintage, which is due to the increase in the concentration of the phenolic compounds. Meanwhile, for the 2020 vintage, the absorbance level decreased in the second maturity wine and immediately increased in the third maturity wine, reaching the levels of the first maturity. Similarly, Chroma (C*), hue (h*), red-greenness (a*) and yellow-blueness (b*) followed the same trend as TPI and CI.

6. Organic acids and glycerol

Organic acids were also measured via HPLC (Table 4). Tartaric acid was found to be present in the highest concentrations, which tended to decrease at higher maturity levels with a clearer trend in the first year. This decrease may be due to the greater maturity and the decrease in concentration of tartaric acid in the grapes, or to the higher precipitation of potassium bitartrate salts in wines with higher ethanol content. Likewise, malic acid decreased significantly with the increase in maturity, while citric acid mostly remained stable, increasing just slightly in the second year at greater maturity levels. Succinic acid showed a clear trend in the first year, increasing with maturity; however, this trend was not so clear in the second year. Moreover, lactic acid concentrations remained very low, as malolactic fermentation did not take place in the base and sparkling wines. In addition, the low concentrations of acetic acid confirm the low levels of volatile acidity (Table 2).

Quantitatively, Glycerol is the third major product of alcoholic fermentation, after ethanol and carbon dioxide, with its formation occurring during glyceropyruvate fermentation. It was originally thought to significantly affect the sensorial characteristics of wines. As expected, its concentration was higher in the higher maturity wines in both years (Table 3).

7. Multivariate statistics

Due to the large amount of data generated throughout this study, a principal component analysis (PCA) was performed using all wine data (conventional wine analysis, foam properties, colour parameters, phenolic characteristics, volatile compounds and organic acids), in order to reduce the dimensions and achieve a better understanding of the results as a whole. PCA is a dimensionality reduction technique that is employed to reduce a large dataset (*i.e.*, a large number of variables) to a more coherent and smaller dataset, while maintaining most of the 'principal' information. Here, despite the fact that a discrimination between the two vintages was evident (Figure 3), a more in-depth analysis was needed. Therefore, PCA was performed on the data from each vintage separately (Figures 4 and 5) in order to identify the parameters which had the most influenced on the produced Savvatiano sparkling wines. A multivariate statistical analysis such as PCA allows the sparkling wine samples to be separated into three different groups for each year. Unsupervised classification using principal component analysis showed a separation of the wines by maturity level (Figure 1-3). Biplots 1, 2 and 3 explained 57.29 % (Figure 3), 80.68 % (Figure 4) and 73.31 % (Figure 5) respectively of the variation of the data. Variables in the score plots were coloured according to maturity level.

The score plot (Figure 3) clearly shows a distinction between the sparkling wines from the 2019 and 2020 vintages, highlighting a significant influence of the vintage on their profiles. More specifically, it can be ascertained that the characteristics of the wines indicated that vintage constituted the principal factor for discrimination, resulting in a separation along the PC1 axis. Organic acids (tartaric, citric,

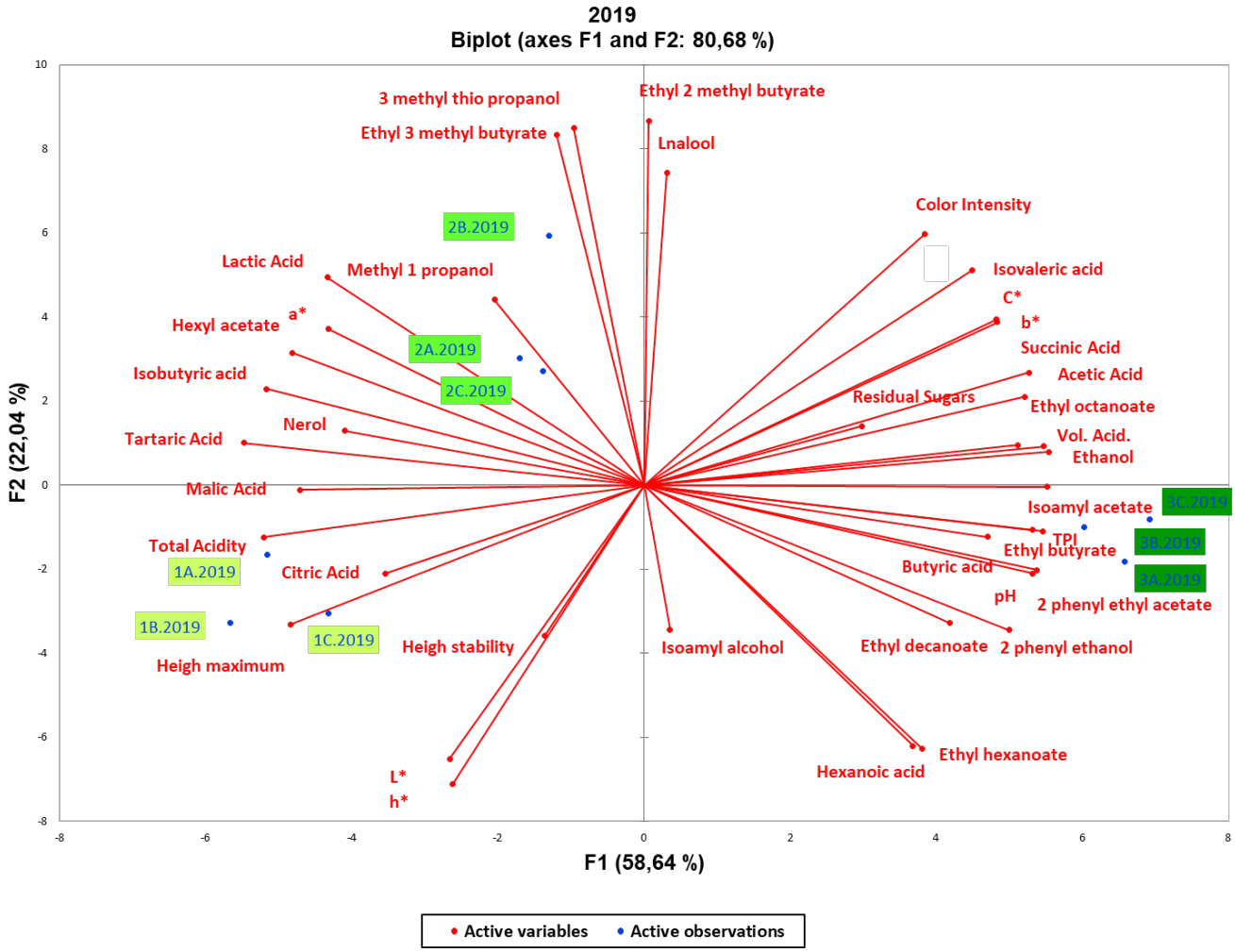


FIGURE 3. Unsupervised classification using a principal component analysis on all wine data (conventional wine analysis, foam properties, colour parameters, phenolic characteristics, volatile compounds and organic acids) from produced sparkling wines of the cultivar Savvatiano, depending on different maturity levels (1st, 2nd and 3rd) for both years (2019 and 2020). The maturity levels of the samples are represented by different shades of green. The length of the arrows is proportional to the contribution of the respective parameter to the overall sample distribution.

lactic and malic acid), total acidity, and both the terpenoid (nerol and linalool) and foam properties are located on the right side of the PCA (Figure 1), while the colour parameters, phenolics, most of the volatile acids, acetic acid and pH are on the left side. This clearly shows that terpenoid and organic acid content increased and that the acids, pH and colour parameters significantly decreased with increasing alcohol content (higher level of maturity) (Figure 3). The effect of the maturity level was also evident, as there is a clear separation between the wines produced in each year (Figures 4 and 5). In the PCA plot (Figures 3, 4 and 5), the biological replicates of the sparkling wine samples from the three maturity levels can be seen to be clustered closely together, demonstrating the high stability of the wine parameters and the good reproducibility of the winemaking technique for both vintages (Figures 4 and 5).

The PCA was also used to establish correlations between the different maturity levels in each vintage (Figures 4 and 5). Regarding the 2019 vintage, the first two dimensions explain 80.68 % of the variance, and the first and second maturity levels, comprising higher levels of most of the organic acids, hexyl acetate, isobutyric acid, nerol and foam properties, are well separated from the wines of the third maturity level, comprising higher levels of isoamyl acetate, ethyl butyrate, pH, butyric acid and 2-ethylphenyl acetate. Concerning the 2020 vintage, the first two dimensions of the PCA explain 73.31 % of the variance, and the three maturity levels are clearly separated into three different quadrants. The first 2020 maturity level is in the first quadrant, correlating well with the volatile compounds linalool, ethyl hexanoate, ethyl octanoate and ethyl butyrate, while the second maturity level is located in the fourth quadrant and correlates well with ethyl-2methyl butyrate, 3-methyl-thiopropanol, foam properties, such as height stability, and the colour parameter a*. Meanwhile, the 2020 third maturity level is in the second quadrant and correlates well with higher concentrations of volatile compounds such as ethyl decanoate, 2-phenylethanol and methyl-1-propanol, as well as with wine parameters, such as pH and ethanol content.

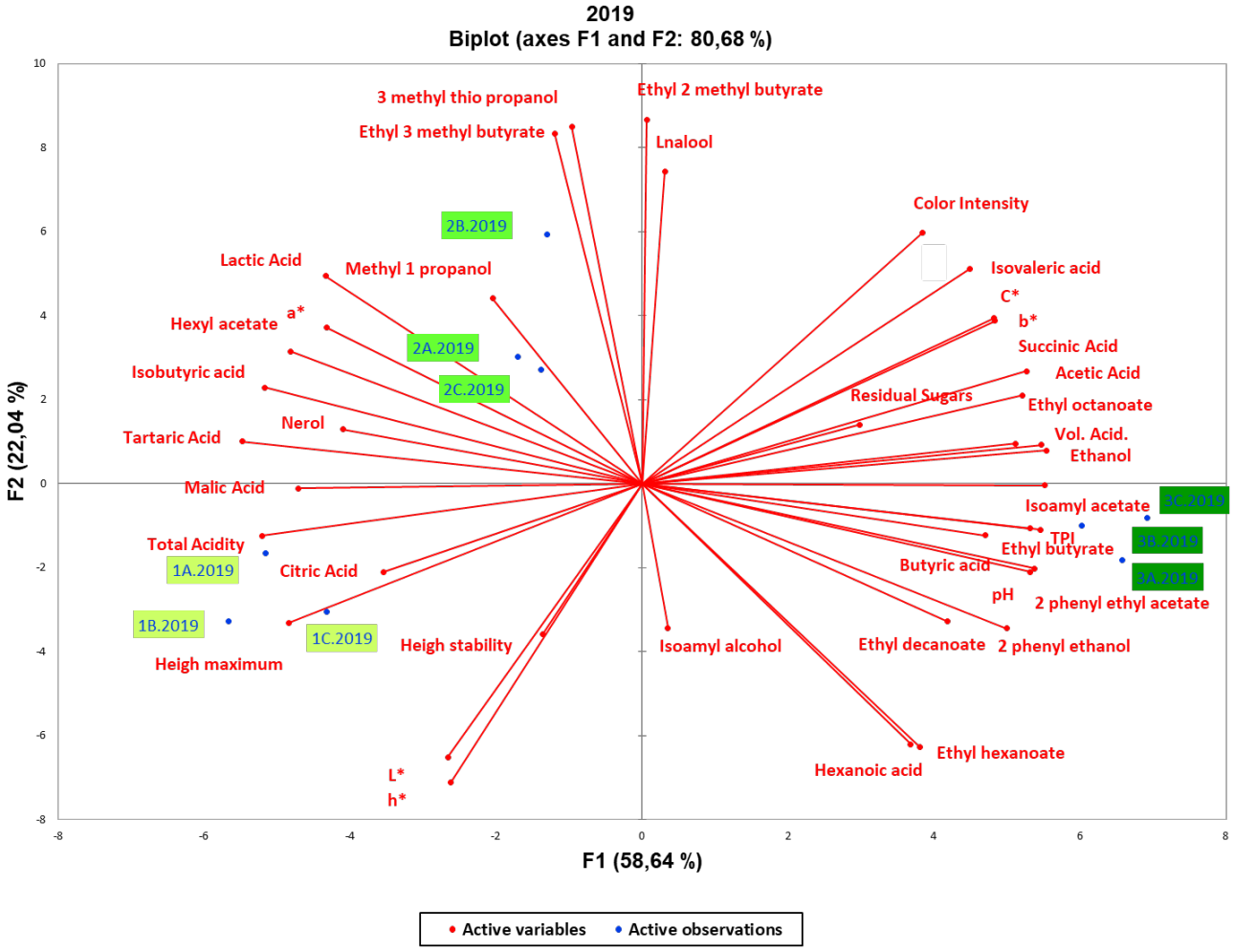


FIGURE 4. Unsupervised classification using a principal component analysis on all wine data (conventional wine analysis, foam properties, colour parameters, phenolic characteristics, volatile compounds and organic acids from produced sparkling wines of the cultivar Savvatiano, depending on different maturity levels (1st, 2nd and 3rd) for the vintage 2019. The maturity levels of the samples are represented by different shades of green. The length of the arrows is proportional to the contribution of the respective parameter to the overall sample distribution.

Therefore, it is evident that the maturity level of the grapes, followed by the alcohol content and pH of the produced wines, plays a major role in wine quality and characteristics and result in different wine styles, even within the same terroir of the Valley of the Muses.

8. Odour activity values

Of the extensive array of compounds that were subjected to meticulous analysis, those exhibiting odour activity values (OAVs) exceeding the threshold value of 1 were deemed significant contributors to the overall aromatic profile of the wine; nevertheless, it is worth noting some studies have even employed a lower OAV threshold of > 0.5 within the context of synthetic model wines in order to construct predictive models of sensory perception (Tao *et al.*, 2010). The application of OAVs serves the vital purpose of elucidating the potential importance and contribution of each individual compound to the aromatic characteristics inherent in wine. However, it is imperative to acknowledge that compounds which exist below their respective detection thresholds may still play a role in influencing the wine's aroma due to the potential for additive-synergistic effects or any emergent properties arising in complex mixtures; conversely, it is also possible for the aromatic intensity of compounds which surpass their detection thresholds to diminish as a result of masking effects (Waterhouse, 2016). Each of the volatile compounds that possessed OAVs greater than 1 was evaluated for its contribution to the aroma of the different wines through a qualitative analysis that utilised the compound's associated sensory descriptor, alongside a quantitative assessment informed by the compound's respective OAVs. Tables S3 and S4 provide a comprehensive listing of the OAVs corresponding to the 19 odour-active compounds present in all of the wines produced during the two distinct vintages under consideration.

Tables S3 and S4 show that, depending on the maturity level, 12 or 13 of the 19 quantified aroma compounds can be found in Savvatiano sparkling wines with OAV > 1. In both vintages, four compounds, namely ethyl octanoate, ethyl hexanoate, isovaleric acid and ethyl butyrate stand out (OAV > 10) and could be principal contributors to the sensory profile of the sparkling wines. Moreover, ethyl butyrate and isoamyl acetate show elevated OAVs for the 2nd and 3rd maturity

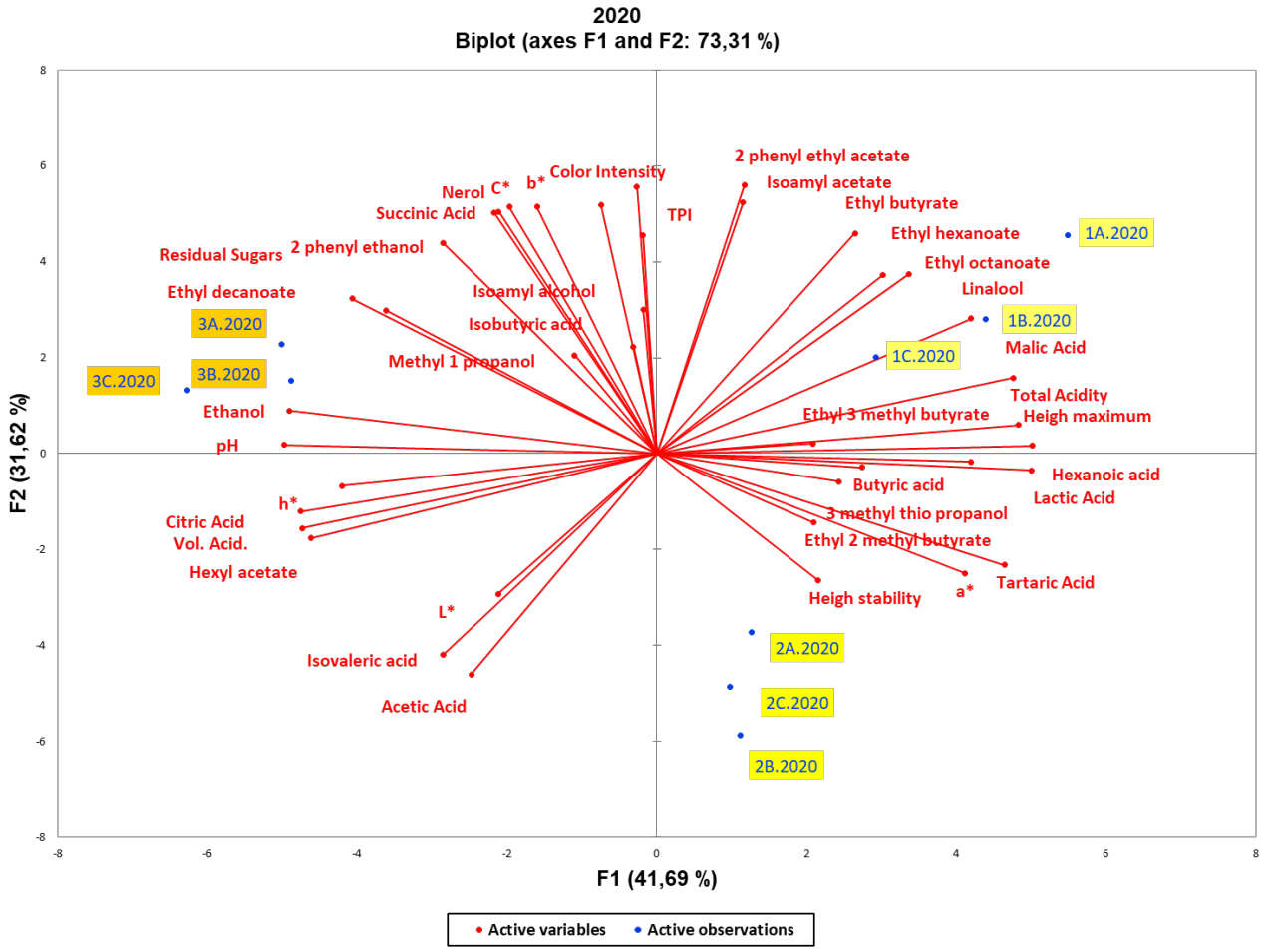


FIGURE 5. Unsupervised classification using a principal component analysis on all wine data (conventional wine analysis, foam properties, colour parameters, phenolic characteristics, volatile compounds and organic acids from produced sparkling wines of the cultivar Savvatiano, depending on different maturity levels (1st, 2nd and 3rd) for the vintage 2020. The maturity levels of the samples are represented by different shades of green. The length of the arrows is proportional to the contribution of the respective parameter to the overall sample distribution.

levels of the first vintage, as well as high OAVs for all three maturity levels of the second vintage (Table S4). Compounds such as ethyl octanoate, ethyl hexanoate and ethyl butyrate are associated with fruity aromas (Ruiz *et al.*, 2019) and have been detected in previous research work on dry wine produced by the Savvatiano grapevine variety (Miliordos *et al.*, 2022; Lola *et al.*, 2023).

All ethyl esters that were successfully identified and detected within the scope of this study exhibited an OAV exceeding the threshold of 1, as detailed in Tables S3 and 4. With regard to the 2019 vintage, all the ethyl esters consistently demonstrated the most elevated levels of OAV in the wines that were made from grapes at the third maturity level, as shown in Table S3. Conversely, in the case of the 2020 vintage, the highest levels of OAV were noted in the wines that were produced from grapes harvested at the first maturity level, with the sole exception being ethyl butyrate, as shown in Table S4.

Focusing on the less desirable aroma compounds, particularly those emanating from volatile fatty acids, hexanoic acid and isovaleric acid exhibited OAV values within the range of 3.1 to 96.01. Notably, the OAV hexanoic acid was a whole order of magnitude greater than that of the other volatile fatty acids, with OAVs ranging from 39 to 96 in the 2019 vintage and (Table S3), and from 32 to 49 in the 2020 vintage (Table S4). Hexanoic acid was followed by Isovaleric acid, which exhibited OAV values in the vicinity of 3.1 to 4.8 in the 2019 vintage (Table S3), and OAV values approximately between 3.5 and 4.5 in the 2020 vintage (Table S4). It is essential to note that volatile fatty acids are compounds that originate from the fermentation process (Escudero *et al.*, 2007), and when their total concentration exceeds 50 mg/L, they have the potential to adversely affect the fruity characteristics that are typically desirable in wine.

It is worth mentioning that the aroma compounds which exert the most significant influence (*i.e.*, those characterised by OAVs greater than 1 exhibited distinct differences among the various wine samples that were produced from grapes of differing maturity levels. Specifically, wines that were produced from grapes at the third maturity level tended to display the highest OAVs across the majority of aroma compound families. This particular finding indicates that, even when adhering to a standardised white vinification protocol, differences in aroma compound profiles can arise due to the maturity level at which the grapes were harvested.

9. Sensory profile

Figure 6 shows the results of the sensory evaluation of the sparkling wines of the Savvatiano variety of different maturities for the 2019 (Figure 6A) and 2020 (Figure 6B) vintages. The statistical analysis of the colour parameters revealed significant differences, confirming that the panelists perceived differences in the colour intensity of the wines, with the highest colour intensity of the sparkling wine of the second maturity being recorded in both vintages (Figures 6A and 6B; Tables S5 and S6). In order to identify the attributes and wines in which significant differences were observed, a Kruskal-Wallis test was performed accompanied by a Mann-Whitney-Wilcoxon Test (Tables S5 and S6). In both years, the wines which were produced by the first maturity level were clearly characterised by the highest foam intensity, but despite this clear trend, no statistical significant differences were found. The results of the sensory evaluation are consistent with those of the physicochemical analyses. The third maturity level tended to have the lowest foam intensity. Regarding foam quality, statistically significant differences were only observed in the first year, being evaluated as highest in the first and third maturity level. In the 2020 vintage, the quality of the foam tended to be highest for the first maturity level. In terms of sensorial attributes, in 2019, the sparkling wines of the first maturity level were evaluated as having the strongest acidity and a tendency for a slightly more marked green apple aroma; these wines also received the highest scores for buttery taste and the lowest for tropical fruits and colour intensity. The sparkling wines of the third maturity level had the strongest aftertaste (Figure 6A and Table S5).

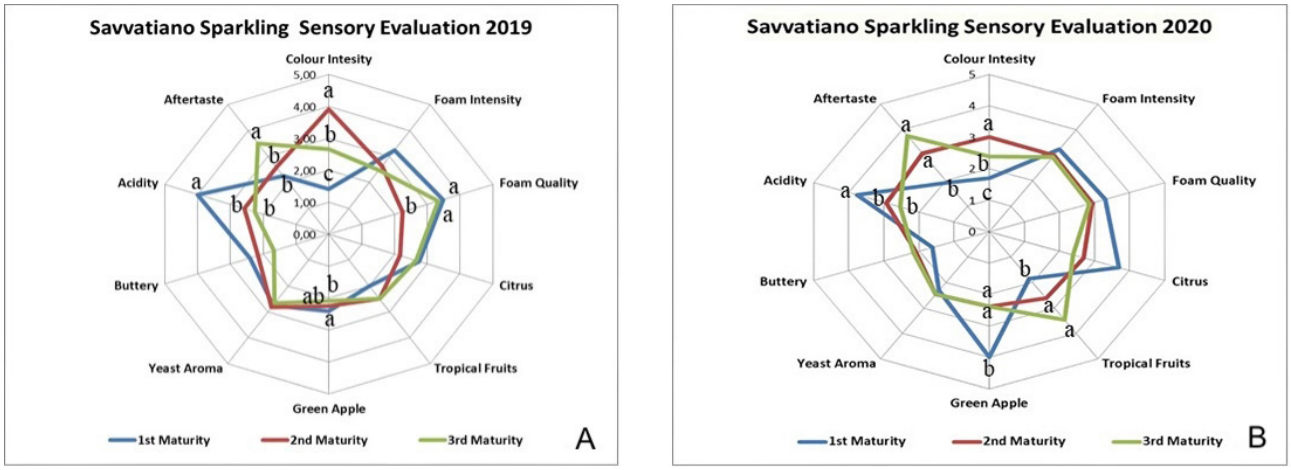


FIGURE 6. Spider plots of the sensory profile of the experimental Sparkling wines from vitis vinifera L. cv. Savvatiano in response to three different maturities. Sparkling Wines were judged using predefined quality attributes on a scale from 1 (absent) to 5 (high). Different Latin letters indicate statistically significant differences between different maturity levels of the same year (Kruskal-Wallis test, $p < 0.05$).

Regarding the 2020 vintage, the sparkling wines of the first maturity level received the highest scores by the judges in terms of citrus and green apple notes, as well as acidity, but the lowest in terms of tropical fruits aromas and aftertaste. By contrast, the sparkling wines of the third maturity level received the highest scores for aftertaste and tropical fruits aromas and the lowest for acidity and green apple aroma intensity (Figure 6B and Table S6).

DISCUSSION

The sparkling wine industry has developed considerably over the past decade due to its high added value, as is also the case throughout the wine sector worldwide. High quality sparkling winemaking is based on the traditional champenoise method. At present, innovative technologies that leverage the unique characteristics of local products are significantly enhancing the quality of enological production. (Berbegal *et al.*, 2017). Domestic and foreign markets are becoming more and more receptive to sparkling wines made from local minor grape varietals (Garofalo *et al.*, 2018).

According to the results of the two years of experimental tests on a white grapevine variety, it is evident that grape maturity level is a key factor affecting the quality of the produced sparkling wine. Evident that the maturity level at which the grapes are harvested is a key factor…; this is important in the context of climate change, which is often the cause of conditions that accelerate grape ripening. The alcohol content of base wines is one of the most critical factors affecting the quality of the foam, being more important than the presence of proteins and polysaccharides (Esteruelas *et al.*, 2015). Sparkling wines produced by base wines that were low in alcohol and from the first grape maturity stage, showed the highest foaming potential, which was confirmed by the sensorial evaluation. These wines also had highest acidity, imparting more harmony and freshness to the final product. Regarding aromatic characteristics, the first maturity-level sparkling wines were distinguished by a more marked presence of green apple and citrus aromas than in the wines of the other two maturity stages. In general, after 15 months in the bottle–a sufficient amount of time for the production of high-quality sparkling wines–significant changes to volatile compounds were observed in the wines from different maturity levels. Meanwhile, wines produced from grapes of highest maturity produced wines with the highest tropical fruits aromatic intensity and the strongest aftertaste. However, the sparkling wines from the 3rd maturity stage lacked balance due to high ethanol content. The scores for 'citrus fruit' and associated sensory descriptors decreased with each of the two successive harvests, whereas the scores for the sensory descriptors categorised as "tropical" increased. Historically, volatile thiols have been identified as the primary compounds responsible for tropical fruit aromas; however, recent findings indicate that wines lacking volatile thiol compounds can also exhibit "tropical" characteristics, with fermentation esters emerging as a viable alternative (Ferreira *et al.*, 1995; Iobbi *et al.*, 2023).

As far as we know, the Savvatiano variety had not been studied for its ability to produce sparkling wines. There have been some attempts, but they are based on empirical knowledge and not on scientific analysis. The variety shows a slightly similar foaming potential to known international varieties, such as Chardonnay (Esteruelas *et al.*, 2015) and has a relatively low aromatic potential (Lola *et al.*, 2023); however, as it is the most cultivated variety in Greece, particularly in Attica and Central Greece, it could be the basis for the production of sparkling wines. Under conditions of global warming, winemakers are concerned about how the degree of ripeness may affect the physicochemical characteristics associated with grape ripening. For this reason, in this work we studied how the ripening of grapes in a warm area–namely, the Valley of the Muses–affects the composition of the wine and, more particularly, its foaming properties, main characteristics and sensorial properties. One of the main conclusions of this study is that the riper the grapes when harvested, the lower the foaming ability of the base wines.

Significant differences were observed in the physicochemical characteristics and volatile composition of the wines produced from the Savvatiano grapes at three different maturity stages and from two consecutive years. The results of the analysis of the volatile compounds showed the differences between the sparkling wines depending on maturity level. Main differences were found in terms of the concentrations of ethyl esters, terpenes and acetate esters. An increased °Brix level in the grapes from later harvest dates leads to an enhanced production of ethanol, as well as higher alcohols, increasing the content of acetate esters (Millán *et al.*, 1992) [Figure 2]. Here, the 3rd maturity showed, in many cases, a decreasing trend in concentration of esters. Nevertheless, it is worth mentioning that major ethyl esters of fatty acids and higher alcohol acetates are strictly fermentative compounds produced by wine microorganisms (Pons *et al.*, 2017). In order to establish the optimal timing of harvest, traditional metrics, such as colour, grape sugar concentration, titratable acidity and pH levels, are routinely determined. However, particular caution must be applied regarding the grapes intended for the production of sparkling wines, as they are typically harvested at a stage of lower ripeness than those used for still wines, and are characterised by relatively low pH values, elevated titratable acidity and low soluble sugar content (Jones *et al.*, 2014; Martínez-Lapuente *et al.*, 2016). Beyond the fundamental chemical evaluations for ascertaining the maturity of the berry, more nuanced profiling of additional chemical categories can be carried out in order to better differentiate varietal grape characteristics and to improve the overall quality of the product. The first maturity-level Savvatiano sparkling wine showed the highest acidity and the best foam quality and the highest intensity of citrus and green apple aromas. Meanwhile, the third maturity-stage grapes produced sparkling wines with the strongest aftertaste, the highest intensity of tropical fruits aroma and the lowest intensity of perceived acidity. It is well known that the qualitative characteristics of foam are one of the most important parameters of sparkling wine. In the present study,

the best foam characteristics were observed in the wines made from the least mature grapes, which is in accordance with Esteruelas *et al.* 2015.

CONCLUSIONS

The results obtained in the present study indicate that Savvatiano is a promising white variety for the production of high-quality sparkling wines, which would increase the oenological potential of this traditional variety currently widely used for the production of dry wines. In addition, it would be interesting to carry out a further study on consumer preferences, due to the fact that a pronounced acidic profile along with floral and fruity aromatic notes is favored in sparkling wines, as these attributes confer a sense of freshness, thereby suggesting that sparkling wines derived from the initial stages of maturation are deemed more desirable.

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