EXTENDED ABSTRACT

Exploring between- and within-vineyard variability of "Malvasia di Candia aromatica" vineyards from Colli Piacentini

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ABSTRACT

Context and purpose of the study. Several studies have demonstrated that climate and soil can be key drivers of variability at different scales. Zoning studies have identified sub-regions that produce distinctive wines, while precision viticulture has recently focused on the within-vineyard scale. Different vigor zones may exhibit variations in canopy growth, yield, and fruit composition, reflecting diverse enological potentials. Although several studies have addressed differences in the technological and phenolic maturity of widespread red varieties, few have explored how variability within and between vineyards affects varietal odorous compounds (VOCs) in terpene-based aromatic white cultivars. This study aims to describe the aroma profile of "Malvasia di Candia aromatica" (MACA) grapes based on vineyard and vigor, assess if and how variability between and within fields affects VOCs during ripening, and identify harvest zones for selective harvesting (SH) at the estate scale.

Materials and methods. The study, conducted in 2018, focused on three variable MACA blocks (V1,2,3), where two vigor zones were identified through visual assessment. For each vineyard, a CRB design was implemented, and nine vines per treatment were selected to evaluate growth, yield, and fruit composition. Technological ripening was monitored weekly in each vineyard. Additionally, grape samples were collected at three stages: pre-veraison, pre-harvest, and at harvest, to quantify free and bound monoterpenes and their derivatives using solid phase microextraction (SPE) combined with gas chromatography–mass spectrometry (GCxGC).

Results. The results indicate variations among vineyards and differing enological aptitudes. Low vigor zones (LV) exhibited lower pruning weight and yield compared to high vigor (HV) areas, which were characterized by heavier, tighter bunches. Grapes from LV had higher total soluble solids (TSS), pH, phenolics, and tartrate levels than the less ripe grapes from HV. Both between- and within-field variability affected grape volatile organic compounds (VOCs) at harvest; LV had higher levels of both free and bound VOCs than HV. Regardless of vineyard and vigor zone, the study confirmed that MACA possesses a monoterpenic profile dominated by geraniol. The findings support the adoption of SH to exploit between- and within-field differences in grape aroma potential through the production of diverse wines.

INTRODUCTION

Numerous studies have highlighted the significant influence of climate and soil on variability across different scales (Van Leeuwen et al., 2020; Bramley et al., 2020), with soil playing a crucial role in smaller local scenarios (Gatti et al., 2022). A straightforward definition of wine terroir emphasizes how the vineyard environment shapes grape and wine quality (Deloire et al., 2005). Traditionally, this understanding is based on interpreting vineyard responses to changes in climate and soil properties within a specific district. Bramley et al. (2020) discussed how new spatial analysis methodologies can enhance our understanding of terroir across various scales. Consequently, in recent decades, zoning studies have identified sub-regions that produce distinctive wines, while precision viticulture (PV) has recently concentrated on the within-vineyard scale. Uniform ripening is considered a key component of terroir while within-vineyard, as well as within-vine and within-cluster variability has traditionally been viewed negatively in viticulture, particularly when it affects fruit composition. Indeed, even if different samples share the same mean value (e.g., for TSS, anthocyanin concentration), a higher variance in these variables increases the contribution of both immature and overripe berries, thereby altering the desired traits of the final wine.

Recently, PV has provided powerful tools to create high-resolution maps of vigor, yield, and grape quality, suggesting that undesirable within-vineyard variability could be transformed into an opportunity through the implementation of site-specific management strategies and variable rate technologies, thus becoming a valuable ally in achieving greater vineyard efficiency. Within-field spatial variability has been extensively described using vegetation indices and represented through thematic maps, where these indices are divided into specific vigor zones (Matese and Di Gennaro, 2015). Ground-truthing of vigor maps, conducted using a complex array of sensing technologies, ground resolutions, cultivars, and wine regions, has demonstrated that within-vineyard variability can lead to significant differences in yield and varying grape composition at harvest (Santesteban et al., 2013; Gatti et al., 2022), suggesting that different wines can be produced from grapes harvested from different areas within the same uniformly managed vineyard (Gatti et al., 2021).

Although Scarlett et al. (2014) demonstrated that within-vineyard variation in rotundone concentration in Shiraz grapes was spatially structured and related to soil property variations in a 6.1ha vineyard, few studies have explored how within-vineyard variability affects varietal odorous compounds (VOCs) in terpene-based aromatic white cultivars. Among these, the white cv. 'Malvasia di Candia aromatica' is considered an excellent candidate for studying the spatial variability of grape aroma compounds due to its high responsiveness to vigor and its high monoterpene accumulation in grapes at harvest (D'Onofrio et al., 2017).

RESEARCH OBJECTIVES

The study aims to (i) describe the aroma profile of *Vitis vinifera* L. cv. 'Malvasia di Candia Aromatica' (MACA) grapes at harvest, collected from two vigor zones in different vineyards within the Colli Piacentini wine district (NW of Italy). Given the genetic origin of the grapevine cultivar, which is closely linked to cv. Moscato bianco, only terpenes are considered in this study. Additionally, the study seeks to (ii) evaluate whether and how both between- and within-field variability influence VOCs during ripening, as well as grapevine performance and fruit composition at harvest, and (iii) identify harvest zones for selective harvesting (SH) at the estate scale to enhance the enological potential of MACA grapes and promote product differentiation at the winery.

MATERIAL AND METHODS

Experimental design. The study took place in 2018 at the "La Tosa" winery in the Colli Piacentini area, across three mature vineyards (V1, V2, and V3) planted with mass-selected *Vitis vinifera* L. cv. 'Malvasia di Candia Aromatica'. V1 was established in 1983 on flat terrain, featuring grapevines grafted onto K5BB and trained in a Casarsa system along North-South-oriented rows. V2, also planted in 1983, is situated on an east-facing slope with East-West-oriented rows, characterized by single-cane VSP-trained vines grafted onto 420A. V3, planted in 1981, is located on a West-facing slope with East-West-oriented rows and grapevines trained to GDC.

In each vineyard, two vigor zones (Z) were identified through visual assessment before veraison: low vigor (LV) and high vigor (HV) zones were delineated to facilitate sampling and selective harvesting. A CRB design was implemented within each vineyard, identifying three blocks (B). For each vineyard and ZxB combination, a sampling zone comprising 10-15 grapevines was designated as a replicate. At berry touch, three sentinel vines per replicate were tagged (54 vines in total) for subsequent grape sampling, canopy growth, and yield assessment.

Vegetative growth, yield components, and fruit composition. Harvesting took place on August 27 when the TSS from LV plots exceeded 20 Brix. For each vine, all clusters were counted, and the yield was measured using a portable scale, allowing for the calculation of the mean cluster mass. A representative sample of three clusters was collected from each vine, promptly taken to the laboratory, and processed to determine total soluble solids, titratable acidity, must pH, potassium and organic acids concentration, and total phenolics. After leaf fall, the pruning mass of one-year-old growth was recorded, and the Ravaz index was calculated as the yield-to-pruning weight ratio.

Ripening kinetics. The ripening kinetics for berry weight, must TSS, TA, and pH were monitored weekly from pre-veraison to harvest. For this purpose, 100 intact berries per replicate were randomly collected, excluding sentinel vines. These samples were immediately placed in a chilling box and transported to the laboratory for the subsequent determination of the aforementioned parameters. Additionally, at the same sampling points, a second sample of 150 berries was collected using the same methodology at veraison, mid-ripening, and harvest. Each sample was promptly taken to the laboratory and stored at -20 °C for the later analysis of VOCs.

VOCs determination. Volatile organic compounds (VOCs) were extracted following the method proposed by D'Onofrio et al. (2017). The GC×GC system utilized a Shimadzu Nexis GC-2030, paired with a TQ8040 NX mass detector. The chromatographic analysis was conducted using two columns: an apolar first-dimension (1D) SLB-5ms fused silica capillary column, coupled with a (2D) SupelcoWAX. Helium served as the carrier gas at a constant flow rate of 1 mL min^{-1}. The GC column's temperature program began at 40 °C and increased to 260 °C at a rate of 6 °C min^{-1}. The injector operated in splitless mode at 260 °C, with an injection volume of 1 µL. Detection was performed using electron ionization (EI) mass spectrometry with a 70 eV ionization energy. The transfer line interface was maintained at 220 °C, and the ion source at 260 °C. Mass acquisition ranged from 41 to 350 m/z, with a scanning rate of 1 scan s^{-1}. Compound identification adhered to a triple criterion: i) comparison of retention time with pure standards, ii) identification of compounds without standards by matching their mass spectra and retention times with those in the NIST 08 commercial library (similarity ≥ 80%), iii) matching the linear retention index (LRI) obtained under our conditions with those published for comparable polar columns. Based on prior studies on 'Malvasia di Candia aromatica', only monoterpenes were measured in this research, with their free, bound, and total (free+bound) fractions considered separately. Detected monoterpenes were categorized into four groups, including the most abundant monoterpenes and their derivatives: Geraniol, Linalool, and α-Terpineol. All other molecules were classified as "Other".

Statistics. The results were analyzed using ANOVA, with vineyard (V) and vigor zone (Z) considered as the main factors. If the F-test was significant, the means were separated using the Student-Newman-Keuls method (p=0.05).

RESULTS

Vegetative growth and yield components. Pruning weight was lower in V1, while the most substantial vegetative growth was observed in V2 (491 vs. 876 g/vine). Although this parameter more than doubled in HV plots compared to LV (973 vs. 432 g/vine), the VxZ interaction was significant, and no differences based on vigor were noted in V2. Yield increased with vigor (5.71 vs. 8.58 kg/vine in LV and HV, respectively); however, yield per vine in LV plots was 50% and 62% lower than in HV for V1 and V3, respectively. In V2, plant productivity decreased by 43% in HV due to the proximity to a forested area. When examining the different yield components, V2 was characterized by a smaller number (27) of denser, larger clusters (234g) with bigger berries (2.63g). In contrast, V3 exhibited a higher number of smaller clusters (110g) with smaller berries (2.18g). Differences in yield based on vigor were supported by all the main yield components, as smaller, looser clusters were observed in LV plots. Additionally, berry size was 26% larger in HV compared to LV (2.63 vs. 2.07, respectively).

Fruit composition at harvest. V1 and V2 exhibited similar technological maturity at harvest, being significantly less ripe compared to V3. The must TSS ranged from 15.8 °Brix (V1) to 20.7 °Brix (V3). Compared to V1 and V2, V3 showed lower acidity, both in terms of TA (5.22 g/L) and must pH (3.29). Significant differences in TSS were also noted when comparing vigor zones, with LV grapes having a higher TSS (20.0 °Brix) than those from HV (15.3 °Brix). Notable VxZ interactions were observed for both TA and malate concentration. In LV plots of the three vineyards, small differences in TA were noted (4.59 vs. 5.57 g/L in V3 and V2), but under HV conditions, TA increased from 5.85 g/L (V3) to 8.47 g/L (V2). Similarly, there was high variability in malic acid for both between- and within-vineyard scales. V2-HV had the highest malate concentration (2.98 g/L) among all six VxZ combinations, with HV maintaining 161% (V2) and 107% (V3) higher malate levels compared to LV, due to different fruit zone microclimates influenced by proximity to forested areas and canopy size limiting cluster exposure to sunlight. Conversely, this variable did not differ among the vigor zones of V1, where a synergistic influence of solute dilution and malate degradation in the EW-oriented rows is expected. Ripening curves demonstrated the consistency of results from veraison to harvest.

Monoterpene concentration. A total of 28 monoterpenes and their derivatives were identified in 'Malvasia di Candia aromatica' grape extracts at harvest. Geraniol and its derivatives emerged as the distinctive monoterpenes for this variety, comprising 72%, followed by linalool and its derivatives at 18%, and α-terpineol at 3%, with other molecules making up the remaining 7%. Free monoterpenes constituted only 15.4%, while the glycosylated fraction was the most prominent component. However, free monoterpenes increased to 27.4% for linalool, whereas nearly 96% of α-terpineol was glycosylated. Although V3 exhibited the highest levels of free geraniol and total free monoterpenes at harvest, vineyard conditions did not influence the concentration of bound and free+bound aromas in the grapes; this was consistent with the ANOVA results, which showed no significant VxZ interaction. In contrast, total monoterpenes in LV (13,125 ng/g) were significantly higher than in HV (5,562 ng/g). Consequently, the highest terpene concentration was observed under LV conditions. Specifically, geraniol ranged from 4,076 ng/g (HV) to 9,414 ng/g (LV), while linalool and α-terpineol were nearly 2.5 times higher in LV compared to HV.

CONCLUSION

The study highlighted the diverse enological potential of 'Malvasia di Candia aromatica' grapes from vineyards characterized by significant between- and within-field variability. Canopy growth, yield, and technological maturity were influenced by both the vineyards and vigor zones, while the vineyards had a milder effect on grape monoterpenes. In contrast, vigor zones consistently impacted the concentration of grape aroma at harvest, with both free and bound monoterpenes reaching their peak under low vigor conditions. The study reaffirms geraniol as a distinctive varietal aroma and advocates for selective harvesting to leverage this variability in the production of diverse wines, offering a modern interpretation of the terroir concept.

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TABLES

Table 1. Vegetative growth, yield and fruit composition of 'Malvasia di Candia aromatica' grapes at harvest depending on vineyard and vigor zones.

	Pruning weight (g vine^{-1})	Yield (kg vine^{-1})	Bunch weight (g)	Berry weight (g)	TSS (°Brix)	TA (g L^{-1})	Malate (g L^{-1})
Vineyard (V)							
V1	491b	8.38	228.6a	2.23b	15.8b	6.81a	1.33b
V2	876a	6.16	234.0a	2.63a	16.4b	6.16a	2.06a
V3	741ab	6.89	110.5b	2.18b	20.7a	5.22b	1.38b
Vigour zone (Z)							
LV	432	5.71	181.3	2.07	20.0	5.11	1.07
HV	973	8.58	200.8	2.63	15.3	7.02	2.10
V	*	*ns*	***	***	***	***	**
Z	***	***	*ns*	***	***	***	***
V × Z	**	***	*ns*	*ns*	ns	**	**

****,**,*** significant for p<0.05, p<0.01 and p<0.001, respectively; ns. not significant. Within column mean separation by SNK test at p=0.05.***

Table 2. Total (free+bound) monoterpene concentration of 'Malvasia di Candia aromatica' grapes at harvest depending on vineyard and vigor zones.

	Geraniol and derivatives (ng g^{-1})	Linalool and derivatives (ng g^{-1})	α-Terpineol and derivatives (ng g^{-1})	Other (ng g^{-1})	Total (ng g^{-1})
Vineyard (V)					
V1	6378.3	1657.5	242.6	679.3	8957.7
V2	6771.2	1624.2	221.0	681.0	9297.5
V3	7084.2	1719.6	235.4	735.3	9774.5
Vigor zone (Z)					
LV	9413.7	2379.5	333.7	997.6	13124.5
HV	4075.5	954.7	132.3	330.5	5562.0
V	ns	ns	ns	ns	ns
Z	***	***	***	***	***
V × Z	ns	ns	ns	ns	ns

****,**,*** significant for p<0.05, p<0.01 and p<0.001, respectively; ns. not significant.***