



## **CHEMICAL BOUNDARIES OF WINE IDENTITY: RATIONALIZING GRAPE AND WINE AROMA DIVERSITY FOR IMPROVED TERROIR MANAGEMENT**

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### **Abstract**

**Aims:** Wine perceived quality lies on a number of different factors. Among these, sensory features, which are in turn dependent on chemical composition, play a primary role. There is traditionally a great emphasis on producing wines that have specific sensory profiles, particularly aroma, that reflect identity features connected to the place and the variety of origin. In the case of high quality wines there is also an expectation for enhances longevity. In this paper, we examine the main chemical drivers of wine geographical identity, its relationship with longevity and the (bio)chemical processes leading to their occurrence in wine.

**Methods and Results:** results from different studies are covered, highlighting the importance of understanding the aroma chemical fingerprint of individual wine types in order to manage regional identity/terroir/cru expression accordingly. The contribution of different volatiles to the expression of typical aroma attributes is defined.

**Conclusions:** based on existing knowledge, the possibility to rationalize viticultural and winemaking practices to enhance the expression of aroma-relevant terroir features is limited to a restricted number of grape varieties. For most of the wines produced globally this process is still based on anecdotal observations.

**Significance and Impact of the Study:** aroma chemical components to specific aroma attributes reflecting geographical identity and terroir are identified, in particular for different Italian wines.

**Keywords:** Wine aroma, geographical identity, terroir, terpenes, norisoprenoids, volatile sulfur compounds.

## Introduction

In the current highly competitive wine market, production of wines with distinctive sensory identity results in a unique selling proposition in the global marketplace, providing higher branding opportunities and increased value and revenues (Lecocq and Vissier, 2006; Krebiehl 2014). In this regard, one concept that has drawn considerable attention in recent decades refers to the notion of *terroir*. This French term indicates a sensorially perceptible dimension within a wine, created by the interactions between grapevine, soil type, topography, and climate, and indirectly influenced by the grapegrower/winemaker via viti-vinicultural practices (van Leeuwen *et al.*, 2004; Fischer *et al.*, 1999). As such, *terroir* represents the basis for creation of added value through the definition of regional identity, in particular sensory features. While *terroir* remains a relatively general and somewhat ill-defined notion, an economically more relevant problem at the level of individual producers is the one of vineyard selection for the identification of the so-called *crus*. The latter are vineyards providing grapes able to systematically produce wines with distinctive characteristics of aroma complexity, mouthfeel balance, longevity and recognizable identity. Often speaking, the wines obtained from these grapes are expected to express the characters of the *terroir* of origin, but winemakers can also seek vineyards that are able to express alternative sensory characters. More in general, from the point of view of the selling proposition, a vineyard that systematically gives wines of extraordinary quality and unique sensory features provides the producer with an opportunity to establish himself as the unique provider of a particular wine of absolute quality, and decide the price accordingly (Lecocq and Vissier, 2006; Krebiehl, 2014). In certain countries such as France, an official *cru* classification is formally established and it is associated with wines of extremely high price and unique selling proposition.

Aroma characteristics are considered to play a central role in perception and recognition of specific wine styles, including recognition of *cru* vineyards. However, identification of *crus* and allocation of their grapes to specific high-end wine segments is mostly based on prior and often anecdotal knowledge and tasting of grapes and wines. In the vast majority of the cases, the chemical markers of such unique characteristics, including the ones related to aroma characteristics, remain unknown, so that the process of *cru* selection is not systematically successful and the related decision-making is often biased, in particular in consideration of seasonal variability of grape quality. This results in inconsistent quality from one vintage to another and difficult establishing of brand and commercial success. Recent studies aiming at defining the key element of *terroir* and *cru* have provided further elements highlighting the complexity of this task. Although it is generally accepted that *terroirs* and *crus* result from the interaction between grapevine, its environment and the human factor, objective measurement of these elements has proven difficult. For example, studies of gene expression levels within the grape berries have shown that vintage variables can have greater importance than geographical and soil factors (Dal santo *et al.*, 2013; Anesi *et al.*, 2015), although a *terroir* factor can be also identified. Most interestingly, it was recently shown that, from a compositional point of view, *terroir* features can only be detected and measured in finished wine after a period of bottle storage, whereas in the young wines they are 'hidden' by hitherto unidentified factors (Roullier-Gall *et al.*, 2014). This observation, which is consistent with the anecdotal evidence that the aroma signature of individual *terroirs* and *crus* is only expressed after a certain period of aging, suggests that the process of identification of *cru* vineyards cannot be based exclusively on grape assessment or on the evaluation of grape and young wine composition. It needs to contemplate also the contribution of the aging process, which in the case of red wines represents a central part of the production process.

From a chemical and biochemical point of view, formation of wine aroma is an extremely complex process. Grape aroma compounds that survive the winemaking process contribute to the aroma of the finished wines, and therefore analysis of grape aroma profile is one key element. However, in the majority of *Vitis vinifera* grapes, a large fraction of grape aroma is 'hidden' in the form of odorless precursors, which will be then revealed during the winemaking process (Ugliano and Moio 2006; Ugliano *et al.*, 2014). Therefore, any attempt to unravel the link between grape aroma composition and wine perceived aroma characteristics should also consider this component. Different types of aroma precursors have been reported in grape, mostly glycoconjugates, S-cysteine, and S-glutathione conjugates, which can be transformed by wine microorganisms or chemical reactions to give potent aroma compounds (Ugliano and Henschke, 2009). In addition, microbial transformation (eg alcoholic and malolactic fermentations) generate a large and diversified pool of aroma compounds contributing to wine aroma, including esters, alcohols, acids, sulfur-containing and carbonyl compounds, further broadening the range of metabolic pathways contributing to wine perceived aroma (Ugliano and Henschke, 2009). However, as previously discussed, the study of the above-mentioned components (eg. grape aroma, their precursors and fermentation-derived metabolites) would provide only a partial picture, most likely lacking a number of key elements

associated with the expression of vineyard aroma signature. It is known indeed that, during aging, a number of potent aroma compounds are generated through multiple chemical pathways which include the above-mentioned grape derived aromas and precursors, as well as a number of other metabolites (Ugliano, 2013). Only in recent years the contribution of these has been recognized, so that previously dismissed aroma precursor such as certain amino acids deriving from the grapes and the yeast, some carbonyl compounds deriving from yeast metabolism, and several sulfur compounds also derived from the yeast are now starting to be considered as possible sources of the typical aroma signature of aged red wines (Marchand *et al.*, 2000; Fedrizzi *et al.*, 2012; Ugliano *et al.*, 2012). These compounds can react with each other in the complex wine environment, leading to the formation of a pool of powerful aroma compounds that determine the unique aroma signature of each wine. Accordingly, a comprehensive assessment of the aroma signature of individual vineyards in terms of their potential to give unique wine styles needs to be integrated with the study of the aroma components generated during wine aging, as well as of the related formation pathways.

One key aspect related to the management of aroma-related terroir factors lies in the level of knowledge that is available concerning the varietal aroma signature of wines, namely the aroma compounds that are most relevant to the expression of aroma attributes for a given variety. These compounds will be indeed intrinsically associated with expression of its regional identity features, being grape variety a central element of wine identity. They will also define the aroma boundaries within which grape growers and winemakers will need to operate to effectively manage their processes from the point of view of optimized expression of regional identity/terroir/cru characteristics. For certain varieties, these aroma boundaries are defined to a good extent. For example, in varieties such as Riesling, Gewürztraminer, Sauvignon blanc, Muscat, and Cabernet Sauvignon, the prominent role of compounds such as TDN, cis-rose oxide, polyfunctional thiols and methoxypyrazines respectively has been long established, and viticultural and winemaking practices have been adjusted accordingly. However, these varieties, which are typically referred to as 'international', represent a relatively minor portion of the entire vineyard surface worldwide. In addition, in certain major wine producing countries, for example Italy, international variety contribute marginally to the production of appellation wines (and therefore to characterization of different regional identities and terroirs), which are in large part produced with native varieties for which chemical boundaries are not characterized to any extent. In reality most of the varieties that are more relevant worldwide are likely to produce aromatically 'neutral' wines, namely wines exhibiting aroma profiles arising from the combination of different aroma nuances rather than from single and well defined aroma characters. For these 'neutral' wines, aroma boundaries are much more difficult to define, as they require more extensive aroma chemical characterization and often identification of novel aroma compounds and/or assessment of synergistic/antagonistic effects between families of aroma compounds.

## **Materials and Methods**

The activity of our laboratory has been focused in recent years on the study of the aroma chemical boundaries of different Italian red and white wines and their relationship with geographical identity. In particular, aroma chemical diversity of a range of commercial and experimental wines was investigated by means of different GC-MS techniques across the 2019-2019 vintages, combined with sensory approaches (sorting tasks). The following wine categories were studied: Valpolicella classico, Amarone, Primitivo, Aglianico, Sangiovese, Lugana, Soave, Pinot grigio for commercial wines and Corvina, Corvinone, Trebbiano di Soave for monovarietal experimental wines.

## **Results and Discussion**

The data obtained were used to build a map of concerning the association between aroma compounds, grape varieties and wine regional identity, some of which are summarized below:

- although mostly associated with white wines, terpene alcohols are central to the expression of aroma regional characters of different red wines, in particular minty and balsamic characters related to cyclic terpenes (e.g. cineoles). These compounds are present at very low concentrations in the grapes but increase with fermentation and aging;
- fermentation-derived esters are important components of the chemical boundaries of geographical identity, contributing to discriminate, within the same variety, wines producers in specific sub-areas. This is in large part linked to the levels of naturally occurring yeast available

nitrogen (YAN). Management of this parameter in the vineyard is a central importance to grape composition in relation to terroir expression, whereas additions of exogenous nitrogen in the winery can alter the link between grape and wine characteristics;

- one remarkable component of wine aroma chemical boundaries is related to aging, as wines that have initially similar aroma composition reveal specific varietal patterns after a period of aging. This involves terpenes as well as some low molecular weight sulfur compounds;
- too often geographical aroma identity is 'masked' by the presence of aroma compounds that are not specifically associated with geographical origin.

## Conclusion

In neutral wines, expression of aroma features associated with geographical identity, terroir, or cru, arise from complex interactions between different aroma compounds. In the wines studied these include cineoles and other cyclic terpenes, low molecular weight sulfur compounds, and fermentation-derived esters. Management of fermentation to reduce accumulation of fusel aldehydes and volatile acidity will facilitate expression of aroma features associated with geographical identity. Likewise, control of *Brettanomyces* spoilage yeast as well as of oxidation will become crucial to allow qualitative wine maturation, creating suitable conditions for chemical reactions leading to development of typical aroma profiles.

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