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Sensory evaluation of Protected Designation of origin Wines: Development of olfactive descriptive profile and references

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ABSTRACT

Wines covered by PDO or PGI quality labels have specific sensory characteristics. According to EU regulations, product characteristics (including the sensory description) must be defined in the PDO technical specification and should be verified for their compliance. There exist internationally harmonized quantitative descriptive sensory methods applied to products such as virgin olive oil, with well-defined attributes described in the method itself. Currently, in the case of wine, there is no harmonized international sensory descriptive method that allows comparison of results between different PDOs or laboratories. In this work, a qualitative and quantitative olfactory profile for a broad variety of wines (11 PDO and 37 wine types) and their corresponding reference standards are proposed. The sensory profile obtained can be used both to verify compliance with the technical specifications of the product and to categorize wines by type or region, thus becoming a powerful tool for the wine sector.

1. Introduction

Currently, wine has become a fashionable beverage almost all over the world and is one of the most frequently described beverages, often reported in many newspapers, books and journals (Rodrigues et al., 2020). It is generally accepted that the sensory characteristics of a wine are mainly influenced by the variety and provenance (location and environment of the vineyard), as well as other factors such as viticultural practices and the winemaking process (Souza Gonzaga et al., 2021). The sensory characteristics of a specific wine are linked to the region of origin where it has been produced and can partially explain why people from different cultures or geographical regions vary significantly in terms of their consumption patterns or preferences (Rodrigues & Parr, 2019). This sensory specificity certainly contributes to creating an identity that helps to promote the wines of a region (Duarte & Northcote, 2009). Several studies have shown that consumers perceive the region of origin as an indication of product quality that even influences how much they are willing to pay for a bottle of wine (Souza Gonzaga et al., 2021).

To preserve the cultural, gastronomic and local heritage and guarantee the quality and authenticity of different traditional food products within the EU and across the world, the European Commission created geographical protection systems for products such as Protected Geographical Indication (PGI) or Protected Designation of Origen (PDO) for wine, spirit drinks and agricultural products (OJEC, 1992; OJEU, 2012). Other wine-producing countries, such as Australia, the United States, Argentina and Chile, although initially supported labelling by grape variety and strong proprietary brands (Defrancesco et al., 2012; Rodrigues et al., 2020), are currently applying similar systems to the PDO/PGI, where regions and subregions responsible for wine production are designated, categorized, restricted and protected by regulations (Souza Gonzaga et al., 2021).

In wines, EU Regulation 1308/2013 requires the characteristics (including the sensory description) of a protected product to be defined in the PDO technical specification and to be guaranteed (OJEU, 2013, 2019). In each European country, independent control bodies or government officials (i.e. France) are in charge to carry out a conformity assessment of each PDO type of wine described in the corresponding technical specification. This conformity assessment process, if the technical conditions of the product are accomplished, leads to a final certification of the product. The EU regulations stablishes bodies in charge of controlling PDO products, which should be accredited in

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accordance with ISO 17065 standard (ISO, 2012). The technical specifications contain, as mentioned above, physicochemical and sensory parameters characteristic of the product (for example, in the case of wine, it establishes parameters such as alcoholic strength maximum or an intensity of fruity aromas that must be complied with). Furthermore, it is also regulated that the laboratories in charge of such analysis (both physical–chemical and sensory) must be accredited according to standard ISO 17025 (ISO, 2017b). Accreditation is the internationally recognized tool to prove the necessary technical competence to perform an activity (conformity assessment) and offer reliable results (laboratories) (ISO, 2017b). Having all the steps of the product conformity assessment system well established is fundamental to comply with the regulations and to guarantee the consumer that the wine he/she buys has specific (sensory) characteristics due to its origin (PDO). Conformity with the sensory characteristics of the product as established in the legally approved PDO specification implies the identification of sensory characteristics of the PDO products and defects (characteristics considered negative for the PDO) whose noticeable presence makes them unacceptable for PDO qualification (Pérez-Elortondo & Zannoni, 2021).

There are no standardized methods for evaluating in an objective and homogeneous way the sensory compliance of PDO products in relation to the sensory description in their official specifications. In contrast, there are currently different sensory practices in Europe with respect to PDO products (Pérez-Elortondo et al., 2018). It is therefore necessary to harmonize the definition of attributes and sensory references that allow the characterization of PDO food products and wines (Etaio & Sáenz-Navajas, 2022; Pérez-Elortondo & Zannoni, 2021).

Defining the sensory attributes of wine with a single, clear terminology can be helpful to avoid confusing consumers (Jackson, 2017), and the subsequent application of a rigorous methodology such as quantitative descriptive analysis (Lawless & Heymann, 2010) can be considered an appropriate approach. It is a methodology widely known by the global scientific community and used for the sensory characterization of food products and beverages (Francis & Williamson, 2015). There already exist internationally harmonized quantitative descriptive sensory analysis methods applied to other products, such as virgin olive oil (IOC, 2005, 2018), with well-defined sensory attributes and protocols described in the method itself. Surprisingly, in the case of wine, no similar method has been agreed upon for international use. Instead, traditionally (and generally accepted in the wine sector), a methodology based on a general evaluation of the product has been applied (OIV, 2021). However, new technically rigorous sensory evaluation approaches that respond to the current requirements of European regulations are now needed.

In response to this gap, the aim of this work is to contribute to the development of a harmonized sensory profile with the corresponding references for the sensory attributes included in it. The purpose of the developed approach is to define a protocol for the qualitative and quantitative description of the sensory characteristics of different wine types, which could be applied for the verification of these characteristics against those described in the technical specifications of the product or simply for the characterization of the product itself. For this purpose, this paper focuses exclusively on the olfactory attributes of different wine types described in 11 wine PDOs with a unique and simplified methodology. The development of the descriptive profile and references for the assessment of taste and mouthfeel descriptors was previously published (Gomis-Bellmunt et al., 2022).

The aim of this paper is closely aligned with the theme of this special issue, which celebrates the contributions of Professor Wendy Parr. According to Parr et al. (2002), training has implications for the ability to recognise and name odours. Sensory references contribute to the standardisation of descriptors and their quantification and are useful for the formation of sensory panels. In the same vein, a correct evaluation of sensory descriptors can contribute to define concepts such as typicality, complexity or quality, as discussed by Parr et al. (2020) and Rodrigues & Parr (2019).

2. Material and methods

2.1. Tasters

The selection process of the tasters was made from recruited candidates from the Catalan wine sector. The final sensory panel consisted of 30 selected assessors (12 women and 18 men, aged between 45 and 55 years). The entire procedure has been described in detail in a previous work (Gomis-Bellmunt et al., 2022).

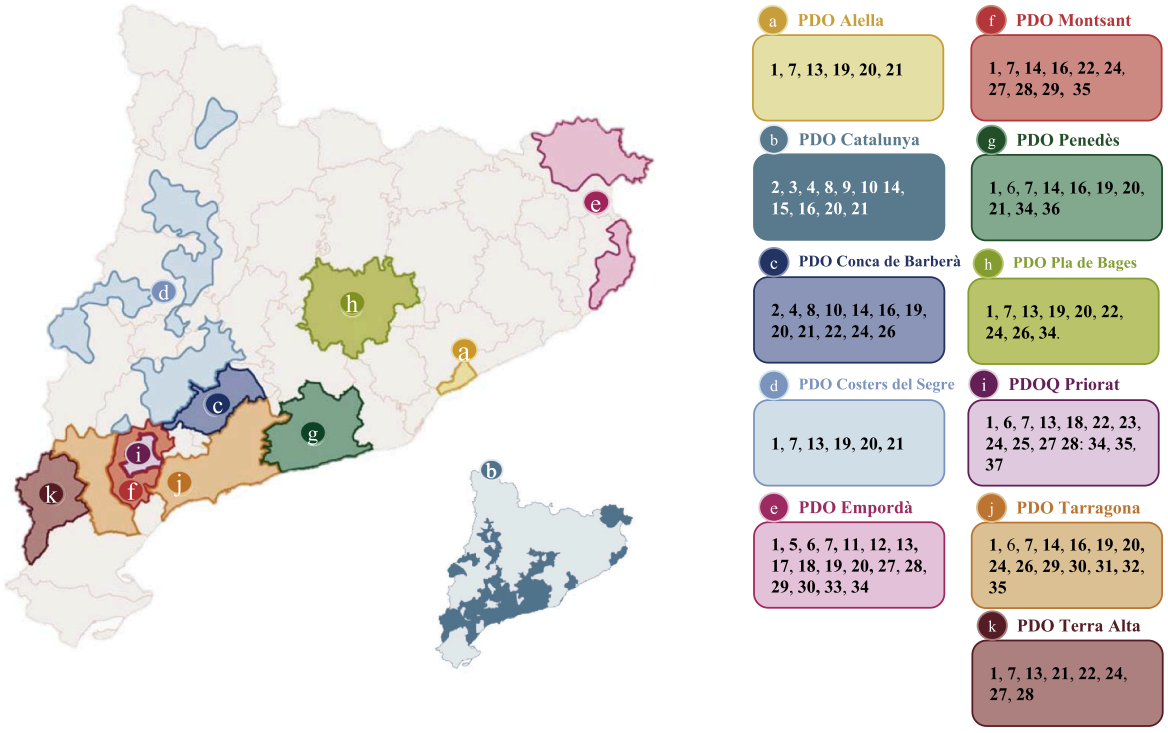
2.2. Olfactory profile

The sensory profile was composed of the sensory attributes mentioned in each of the 11 technical specifications of the Catalan PDOs for different wine types. Fig. 1 shows the territories covered by the PDOs and the type of wines (n = 37) included in the technical specifications of each PDO. The combination of the 37 types of wines with the 11 PDOs produced 114 combinations, since some types were in more than one PDO and not all PDOs had all types. The selection, definition and classification of the lexicon included in the technical specifications to describe the sensory characteristics of each type of wine was carried out through teamwork, similar to that described in the previous published work which focused only on the taste and mouthfeel attributes (Gomis-Bellmunt et al., 2022). It is important to note that the different technical specifications describe the sensory attributes for each type of wine, without taking into account the variety. In addition, the same type of wine can be made with a single variety or with a blend of the different permitted varieties. For this reason, and as the objective of this paper is to describe a methodology suitable for ensuring the compliance with the different technical specifications, those descriptors referring to the different wine types were retained. As an additional information and to make the approach presented in this paper easier to be adopted by other laboratories, a table with the recommended (traditional) and authorized varieties for each PDO is also provided (Appendix A). This paper focuses on the olfactory attributes perceived both via orthonasal and retronasal.

Fig. 2 shows a scheme of the entire methodological process followed, indicating the time spent in each general stage. The teamwork was carried out with the selected tasters, who were led by the panel leader. Tasters were asked to group the descriptors to obtain a classification by aroma families in accordance with their sensory properties (floral, fruity, etc.). In addition, they were asked to name and define each aromatic family, as well as identify synonyms, unclear or subjective terms. The findings of each group were discussed in open sessions led by the panel leader. The aim of the discussion was to reach a consensus on the aromatic families to be assessed and to establish their definition and the attributes that integrate them, including all their synonyms (e.g., aromatic herbs or forest herbs).

2.3. Reference standards development

For the development of the references, each session was held in two parts, one for sensory evaluation of the different references and the other for discussion of the results (Fig. 2). Both quantitative and qualitative references were developed using products in the following order of priority: commercial natural aromas, macerations of natural products and, in case the desired reference was not obtained, natural products. Commercial natural aromas and macerations were presented in all cases in a matrix of synthetic wine (Gomis-Bellmunt et al., 2022). To evaluate the proposed product, samples were presented in a standard transparent tasting glass (DIN, 1981) and covered with a Petri dish. They were served monadically and identified with random three-digit codes. Sensory evaluations were carried out in a tasting room with standardized booths (ISO, 2007). The tasting temperature and room temperature were set to 20 ± 2 °C. In the second part of the session, depending on the type of reference, the results obtained in the first part or in previous sessions were discussed.



1: White wine, **2:** Young white wine, **3:** Low alcoholic white wine, **4:** Aged white wine, **5:** White wine fermented in barrels, **6**: White wine aged in wood barrels, **7**: Rosé wine , **8**: Young rosé wine, **9**: Low alcoholic rosé wine, **10**: Aged rosé wine, 11:Rosé wine fermented in barrels, **12**: Rosé wine aged in wood barrels, **13**: Red wine, **14**: Young red wine, **15**: Low alcoholic red wine, **16**: Aged red wine, **17**: Red wine fermented in barrels, **18**: Red wine aged in wood barrels, **19**: Quality sparkling wine, **20**: *Vi d'agulla* (sparkling wine), **21**: Liqueur wine/ fortified wine, **22**: Natural sweet wine, **23**: Sweet liqueur wine, **24**: *Ranci* wine (Sherry stile wine), **25**: Sweet *Ranci* (Sherry stile wine), **26**: *Mistela* wine (fortified wine), **27**: White *mistela* wine (fortified wine), **28**: Red *mistela* wine (fortified wine), **29**: *Garnatxa* wine (fortified wine from Grenache grape), **30**: *Moscatell* wine (fortified wine from Muscat grape), **31**: *Classic DO Tarragona* (fortified wine), **32**: *Vi de missa* (Sacramental wine /fortified wine), **33**: Sweet wine, **34**: Late harvest wine, **35**: *Vimblanc* (Sweet wine), **36**: *Dolç de fred* (Ice wine), **37**: *Vi de finca* (Single Vineyard Wines).

Fig. 1. Map of the 11 Catalan Protected Designations of Origin containing the types of wines specifically included in the specifications of each PDO (letters a-k indicate the PDO wine and numbers 1–37 wine typologies).

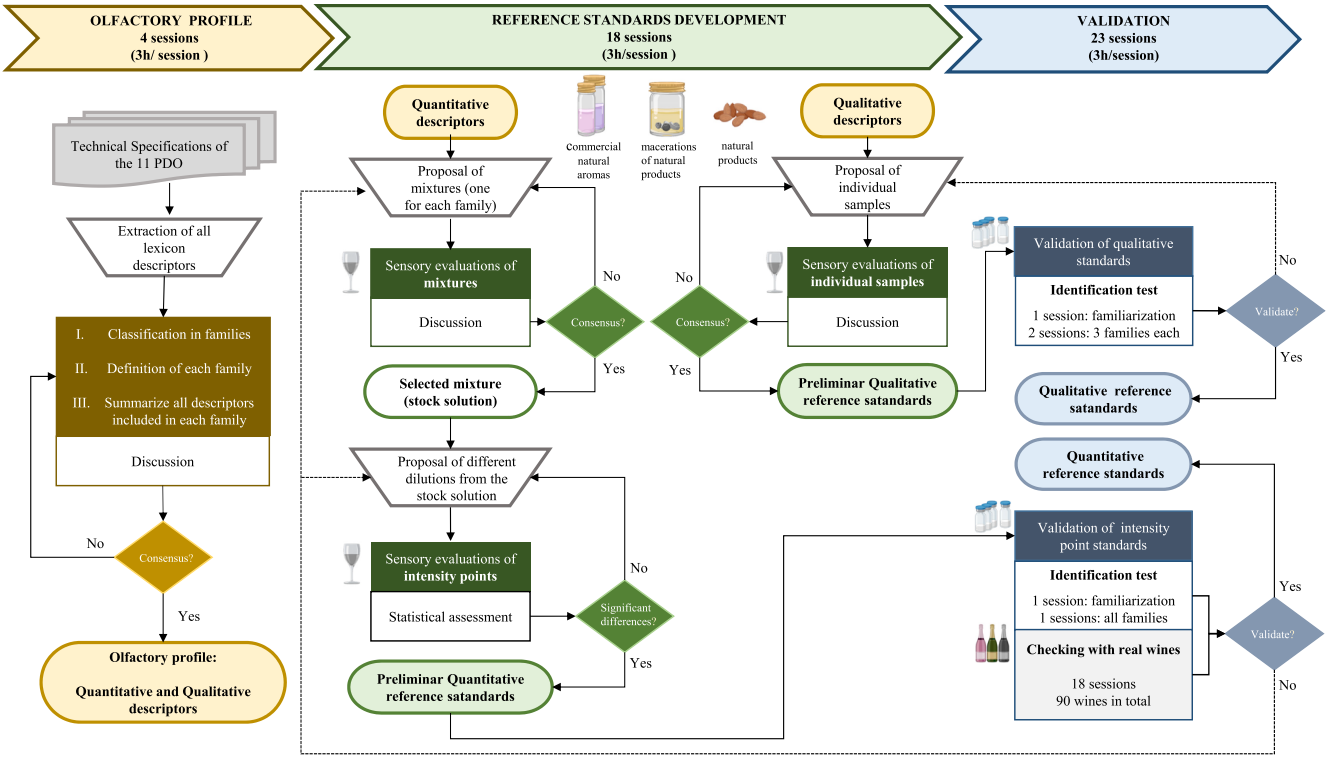


Fig. 2. Scheme of the process followed to obtain the olfactory profile, the development of reference standards for each attribute and their validation.

2.3.1. Quantitative reference standards

First, as shown in Fig. 2, several mixtures of individual references were proposed to obtain potentially representative standards for each of the six quantitative attributes (families). In each session, these mixtures were presented to the tasters, and they were asked to rate their suitability (similarity to the corresponding family or complex descriptor in a real wine sample). For this purpose, a ranking scale was used where tasters were asked to rank the mixtures according to the perceived degree of suitability between 1 (the least suitable mixture) and 4 (the most suitable). Tasters did not have a real wine at their disposal but made use of their own mental references. The answer sheet contained the definition of the attribute to be assessed and the terms included in it. Tasters were allowed to add any comments they considered necessary to improve the mixture. All the scores and comments of the tasters were considered to prepare a new set of mixtures to be tested in the next session. This process was repeated until a mixture with a high degree of suitability was obtained (consensus of at least 70 % of the tasters). All the mixtures presented and evaluated for each quantitative attribute are available in Appendix A.

Once the right mixture for each family was selected, 5 intensity points were obtained by diluting (1:2) from a concentrated stock solution. The diluted references were presented to the group of tasters, who had to quantify the intensity (semistructured linear scale of 15 cm anchored at the beginning with a 0: undetectable, and at 10 cm: maximum intensity potentially detectable in a wine, leaving the possibility of marking above this maximum when the intensity was considered excessive. Subsequently, statistical analysis of the data obtained by means of a two-factor analysis of variance (ANOVA) (product and taster) was performed. Based on the results obtained, the dilutions were adjusted by consensus until three or four points of intensity were obtained on the scale for each of the families.

2.3.2. Qualitative reference standards

For the elaboration of the qualitative references, in the case of commercial natural aromas, the starting proposed sample was a mild perceptible concentration of the product, according to the research team's judgment. Tasters were asked to identify the aroma of each of the presented samples. The answer sheet used allowed tasters to indicate whether the sample was suitable (to represent the specific attribute in wine) or not and to add any needed observation, i.e., whether the concentration was insufficient, correct or excessive compared to that perceived in a real wine. They could also note down other contributions/modifications to improve the presented reference. At the end of the session, the answer sheets were collected, and the most representative samples and which ones should be discarded were decided by consensus after group discussion (agreement of at least 70 % of tasters). In the case that a sample was not suitable or required modifications, a new proposal (change of commercial product, maceration, mixture of different composition or natural product) was presented in the following session, and the process was repeated until a consensus was reached on the suitability for this specific wine attribute. In each session, one aromatic family was worked on. A large number of products, mixtures and macerations were tested for the development of the qualitative attribute references included in each family. For more detailed information, see Appendix A.

To develop references for the "frankness" concept, i.e., absence of defects, a specific session was held focusing on the main wine alterations or off-odors (OIV, 2016). According to the perception thresholds previously published (Francis & Williamson, 2015; Lambrechts & Pretorius, 2000; Dubourdieu & Tominaga, 2009; Goniak & Noble, 1987) or the concentrations indicated directly by the supplier, several references were prepared. These references were presented to tasters, who were asked to identify the attribute (and/or the compound causing the off-odour) and to assess whether the concentration was insufficient, appropriate or excessive. As the same defect can be produced by different compounds, several references were selected to represent the same off-odour. For example, in the case of reduced, ethanethiol gives one type of aroma and hydrogen sulphide a different one, and both are considered reduced; therefore, two separate references were available to show the same attribute. All concentrations and odorant molecules tested are included in Appendix A.

2.4. Validation of reference standards

A validation study of the qualitative and quantitative references was carried out through an identification test. Tasters carried out the test in two phases: a first phase in which the tasters had unlimited time for familiarizing and memorizing the aroma of all the references and a second phase in which they had to recognize and identify all the references in a blind test. In the case of qualitative reference standards, to validate a reference, correct identification by at least 90 % of the tasters was needed. Regarding quantitative references, all intensity point standard references from the different families were presented together. Tasters had to identify the aromatic family and quantify each sample on a 10-point intensity scale. To consider the qualitative references valid, the maximum number of identification errors allowed per taster was 4 (10 %), which was considered correct for 67 % of the tasters. For the quantitative references, a minimum deviation of 10 % with respect to the assigned intensity value was required for a minimum of 67 % of the tasters.

All references were presented in 100 ml glass vials with airtight screw caps and labelled with a random three-digit code. Each flask contained 50 ml of the reference solution. The references were delivered in individual boxes for each taster and were assessed in a sensory room equipped with individual sensory booths (ISO, 2007). Subsequently, and between sessions, they were kept in cold storage at a temperature between 4 °C and 10 °C.

In addition, to validate the suitability of the points of the intensity scales obtained, commercial wines with potentially high values of the family to be validated were used. For each family (or quantitative attribute), wines of different types (white, red, sweet, sparkling, etc.) and with different qualitative descriptors were tasted to verify that the tasters detected and quantified them correctly. For example, to validate quantitative attributes of floral aromas, potentially floral wines were selected with aromas of different types of flowers: rose, violet, orange blossom, iris, lily, etc. Wines from the PDOs under study and from other PDOs known to have wines with extremely high aromas were used, such as the Gewürztraminer variety from PDO Somontano, which turned out to have a high value on the floral scale in the case of white wines. The performance and agreement of the tasters was checked according to ISO 11132 (ISO, 2017a).

2.4.1. Statistical analysis

To determine the intensity value for each quantitative reference and its suitability, a two-way ANOVA was performed including the different concentrations and tasters as fixed factors. Tukey's honestly significant difference (HSD) post hoc test was used to explore the existence of significant differences among the different concentrations ($p < 0.05$). In the validation process, different one-way, two-way and three-way analyses (including as fixed factors for each reference/attribute the product/concentration and tasters and the session as a random factor) were performed according to the recommendations and procedure described in ISO 11132 (ISO, 2017a).

All statistical analyses were performed using XLSTAT software, version 2020.1 (2020) (Addinsoft, Paris, France).

3. Results

3.1. Olfactory profile

The descriptors included in the sensory profile developed in this study are represented in Fig. 3. This profile includes both the olfactory

Fig. 3. Aroma wheel of wines from the 11 PDOs wines of Catalonia.

families to be assessed quantitatively and the qualitative attributes. The profile is grouped into six main aromatic families corresponding to the quantitative attributes, other aromas (mineral and alcoholic notes/ warm) and one more group where the possible alterations of the wine can be found.

Table 1 shows the information about the quantitative attributes obtained, and Table 2 shows those attributes not included in any aromatic family.

To define the term frankness (or absence of off-odours) and take into account the contribution of this attribute in the overall profile of each wine, the following seven off-odours were chosen*: volatile anisoles* (defined as the olfactory sensation associated with the excess of chlorinated anisole compounds such as trichloroanisole (TCA) and its derivatives); *volatile phenols* (defined as the olfactory sensation associated with the presence of 4-ethylphenol and 4-ethylguaiacol molecules produced in the metabolism of the microorganism *Brettanomyces*); *oxidation* (defined as the olfactory sensation associated with the excess of substances of aldehyde origin); *reduction* (defined as the olfactory sensation associated with excess sulphur-derived chemical compounds, mainly hydrogen sulphide, mercaptan or other derivatives); *volatile acidity* (defined as the olfactory sensation associated with excess ethyl acetate and acetic acid); *vegetal* (defined as the unpleasant olfactory sensation associated with green vegetables such as green pepper, asparagus, green beans) and *moldy/earthy* (defined as the olfactory sensation associated with humidity or wet earth odour).

On the other hand, some parameters were calculated mathematically from the sensory evaluated attributes (see Appendix B). These are concepts such as olfactory complexity or freshness that provide complementary information to the profile, even if these terms have not been directly evaluated by the tasters.

3.2. *Reference standards development*

3.2.1. *Quantitative reference standards*

Table 3 shows the mixtures selected for each attribute and the concentration of each component from which the stock mixture was prepared. Table 3 also contains the dilutions to be made to achieve each intensity point. For each attribute or family, 3 to 4 intensity points (indicating low, medium and high intensity) on a 10-point scale were established. There were significant differences ($p < 0.05$) between the different points of the scale for all of the quantitative attributes.

Table 1
Selected quantitative attributes (families) and definitions, qualitative attributes included in each family and definitions, associated terms (synonyms), PDO and type of wine that is described in the technical specifications.

Name of quantitative attribute or family	Definition of families	Name of qualitative attributes included and codes of the wine type and PDO that contain them	Definition of generic qualitative attributes	Associated terms and codes of the wine type and PDO
Floral	Odour related to the smell of fresh or dried flowers.	White flowers: h1, h20 Sweet flowers: j26, j29, j30, j35, j32, j31 Rose: j26, j29, j30, j35, j32, j31 Jasmine: j26, j29, j30, j35, j32, j31	*White flowers* includes any flower such as citrus blossom, orange blossom, iris or lily. *Sweet flowers* includes any flower such as almond blossom, violet, rose or jasmine.	Floral notes: a1, a13, b3, b2, b8, b20, c2, c8, c20, d1, d7, d13, d19, d20, d21, e7, e27, f7, h19, i1, i7, i13, i22, i23, i27, i28, j2
Aromatic and forest herbs/ balsamic	Odour related to aromatic herbs (such as Rosemary, Thyme) and forest herbs present in the Mediterranean forest (such as lavender, anise, eucalyptus, mint and /or liquorice) or with spices.	Aniseed notes: h1, h20 Spicy: d1, d7, d13, d21, f2, f4, i6, i22, i23, i27, i28, j24 Lavender: h1, h20 Eucalyptus: h13 Mint: h13 Liquorice (root): a13	*Aniseed notes* includes any plant aroma such as fennel or anise. *Spicy* refers any species such as pepper, cloves or nutmeg. *Liquorice* in this case refers to the edible root of the plant.	Aromatic forest herbs: h13, a13 Balsamic aromes: e3, e4, k1, a13, f13, h13, j16 Wild herbs: h13 Aromatic vegetable herbs: d1, d7, d13, d19, d21
Fruity	Odour related to fresh fruit with different ripeness (such a ripe fruit)	Acid/citrus fruit: f27, f28, f29, h1, h19, h20 White fruit: g1, g19, g20 Forest fruit/black fruit: a13, b13 Red fruit: a7, e11, e28, g7, g13, h7, h20, j13 Strawberry: j7, f7 Mature cherry: f7 Peach: j7 Tropical fruit: g1, g19, g20	*Acid fruit* refers any fruit such as lemon, orange, pink grapefruit, blood orange or tangerine. *White fruit* refers any fruit such as pear or apple. *Black fruit* refers any fruit such as cranberries, blackberries, gin or cassis. *Red fruit* refers any fruit such as strawberry, wild strawberry, cherry, raspberry or currant. *Peach* includes the types vineyard peach, water peach, nectarine or white peach. *Tropical fruit* refers any fruit such as litchi, pineapple, mango, banana or passion fruit.	Fruit notes: a1, a20, a19, b3, b2, b8, b14, b15, b20, b21, c2, c8, c14, c19, c20, c21, e5, e6, e7, e11, e12, e13, e17, e18, e19, e20, e27, f7, g7, g19, i1, i6, i7, i13, i22, i23, i27, i28, j2, j7, j19, j20. Mature fruit: c22, c26, e29, e33, e34, f1, f13, g6, g34, j4, j13, j26, j29, j30, j35, j32, j31
Aging	Odour that comes from the aging and the conditions to which the wine is submitted during this time.	Vanilla: b4, b10, b16, c4, c10, c16 Wood/ barrels notes: e5, e6, e12, j4, j16 Toasted, smoked, empyreumatic: a13, b4, b16, c4, c10, c16, j4, j16 Aldehydes/ethanal: b21, c21, h24, i24, i25 Liquorice (candy) : a13 Toasted nuts: b21, c24, e34, f28, h19, h34, h22, h24 Hazelnut: f24, j14	*Liquorice* in this case refers to candies or sweets made with the extract of this plant. *Nuts* refers any fruit such as almonds, hazelnuts, walnuts or pine nuts.	Aging: e19, g6, g21, g36, i24, i25
Lactic and post-fermentation	Odour resulting from the autolysis of yeast and/or the action of lactic bacteria.	Pastry/confectionery: f28, h22, h34 Bread notes: h19 Lactic: i1 Lees (breeding on lees) : h19	*Pastry* or *confectionery* refers to the aroma of any product such as dairy, butter biscuits, butter, cream, brioche, leaf paste or caramel. *Lactic or dairy* products refers to any product such as raw milk, yoghurts, fresh cheese or cheese.	Lactic notes: i1
Processed fruit, over- mature fruit, and honey	Odour of honey and/or fruit that has been subjected to a process of concentration of sugars, such as dehydration, sugar syrup or compote.	Jam/marmelade f29, g21, g34, g36, h7, h20 Grape jelly e34 Syrup h22, h34 Quince jelly f29 Fig fruit h24, h26 Raisin; c22, c26, f13, h22, h24, h34, j26, j29, j30, j35, j32, j31 Dried apricot: f1, h19	*Mellow/silky* includes the aromatic complex produced by aromas of raisins, honey and ripe fruits	Dried fruit: i22, i23, i24, i25, i34 Seasoned (defined as subjecting to a slow rest and maturation after drying in order to develop its taste): a13, f13, b16, c16, j16

(*continued on next page*)

Table 1 (*continued*)

Name of quantitative attribute or family	Definition of families	Name of qualitative attributes included and codes of the wine type and PDO that contain them	Definition of generic qualitative attributes	Associated terms and codes of the wine type and PDO
		Dried dates; j26, j29, j30, j35, j32, j31 Orange peel h22 Melon/ripe melon: h26 Grape h26, i27, i28, j29, j35, j32, j31, k22, k26, k27, k28 Mellow/silky & honey: c22, c26, f1, f27, f28, h22, j26, j29, j30, j35, j32, j31		

a: PDO Alella, b: PDO Catalunya, c: PDO Conca de Barberà, d: PDO Costers del Segre, e: PDO Empordà, f: PDO Montsant, g: PDO Penedès, h: PDO Pla de Bages, i: QPDO Priorat, j: PDO Tarragona, k: PDO Terra Alta,
1: White wine, 2: Young white wine, 3: Low alcoholic white wine, 4: Aged white wine, 5: White wine fermented in barrels, 6: White wine aged in wood barrels, 7: Rosé wine, 8: Young rosé wine, 9: Low alcoholic rosé wine, 10: Aged rosé wine, 11:Rosé wine fermented in barrels, 12: Rosé wine aged in wood barrels, 13: Red wine, 14: Young red wine, 15: Low alcoholic red wine, 16: Aged red wine, 17: Red wine fermented in barrels, 18: Red wine aged in wood barrels, 19: Quality sparkling wine, 20: *Vi d'agulla* (sparkling wine), 21: Liqueur wine/ fortified wine, 22: Natural sweet wine, 23: Sweet liqueur wine, 24*: Ranci* wine (Sherry stile wine), 25: Sweet *Ranci* (Sherry stile wine), 26*: Mistela* wine (fortified wine) 27: White *mistela* wine (fortified wine), 28: Red *mistela* wine (fortified wine), 29*: Garnatxa* wine (fortified wine from Grenache grape), 30*: Moscatell* wine (fortified wine from Muscat grape), 31*: Classic DO Tarragona* (fortified wine), 32*: Vi de missa* (Sacramental wine /fortified wine), 33: Sweet wine, 34: Late harvest wine, 35*: Vimblanc* (Sweet wine), 36*: Dolç de fred* (Ice wine), 37: *Vi de finca* (Single Vineyard Wines).

3.2.2. Qualitative reference standards

Table 4 shows the compounds and concentrations selected for qualitative references and indicates the quantity provided to each taster for training. Qualitative references were also developed to evaluate the frankness or absence of defects (Table 5). For each off-odour, different compounds are shown having a different aroma but included in the same defect.

3.2.3. Validation of reference standards

Regarding the results obtained in the identification test applied to the qualitative and quantitative references, the percentage of correct identification varied between 92 % (4 mistakes) and 96 % (2 mistakes) for qualitative references, and for quantitative references, 97 % (the established criterion was 67 %) of the tasters obtained a deviation of less than 10 % (which would be equivalent to a deviation of one point on the scale).

The results obtained in the validation process with commercial wines of different types agreed with those described in ISO 11132 (ISO, 2017a). The results obtained were repeatable (repeatability index lower than 0.9700), reproducible (reproducibility index lower than 0.9701), and discriminant ($p \leq 0.05$) between wines for all the sensory descriptors, and centroids obtained through a discriminant analysis were grouped according to wine type, obtaining 70 % correct classification on average in the confusion matrix (minimum criterion set at 67 %). The homogeneity index of the panel in all cases exceeds the critical value of 1.1, so it can be concluded that the panel is homogeneous as a whole, and the references were validated. For the qualitative references, the repeatability percentage exceeded the minimum established of 75 % for all attributes (ranging from 77 % to 87 %), the reproducibility percentage was higher than 70 % (minimum established) for all attributes (ranging from 75 % to 83 %) and for the discriminant capacity, the tasters found significant differences ($p \leq 0.05$) in 88 % (higher than the established 75 % as minimum) of the qualitative attributes.

4. Discussion

4.1. Olfactory profile

PDO is part of the regulated quality schemes in the European Union (EC. 2023). However, there is no standardized approach for the development of sensory control methods for PDO wines, and the wide diversity of methods used among PDOs manifests the need to harmonize technical criteria and references (Pérez-Elortondo et al., 2018). An essential harmonization step is to describe the sensory characteristics of the products involved and the use of appropriate terminology for controlling them. In the literature, there are many papers where the aromatic phase of wine is studied, presenting different classifications and reference materials. The best known are the fragrance charts, first developed for beer by Meilgaard et al., (1979,1982) or the "Wine Aroma Wheel," (Noble et al., 1987), which have subsequently been adapted for the characterization of whiskies (Lee et al., 2001). Jackson (2017) compiled most of the reference materials for representing wine aromas used by different research groups. On the other hand, there are many works on the aromatic characterization of varietal wines from very specific areas (Schlosser et al., 2005; Schüttler et al., 2015; Gomes et al., 2016; Sánchez-Palomo et al., 2017, 2019). Authors such as Etaio et al. (2010, 2012) go a step further by describing the methodology to test the quality of young red wine from Rioja Alavesa or Txakoli considering the main sensory attributes. In the same vein, Le Menn et al. (2021) recently developed a sensory methodology that allows for categorization of champagne reserve wines. This paper proposes, for the first time, an approach for the development of a sensory profile and reference materials that allows the sensory evaluation of wines from 11 PDO and 37 wine types and that can be extrapolated to any type of wine and origin.

To obtain the olfactory profile, given the wide diversity of products and lexicon, the main task was to reduce the number of descriptors used in the technical specifications, to define them and to group them into six aromatic families, with an additional classification for some aromas that, due to their characteristics, did not fit into any of the families. In the technical specifications, there are synonymous terms referring to the same attribute (e.g., aromatic herbs, forest herbs, wild herbs, aromatic vegetal herbs) or, on the contrary, ambiguous (or subjective) terms and even some emotional (or poetic) terms. A rigorous definition of all descriptive terms used is essential for a final objective evaluation (Etaio & Sáenz-Navajas, 2022).

The grouping into seven main olfactory families is a simplification with respect to the 9 groups of aromas proposed by Jackson (2020), the 9 groups proposed by Razungles et al. (1993) or the 12 groups of the Wine Aroma Wheel adopted by the American Society for Enology and Viticulture, originally described by Noble et al. (1987). The combination of quantitative and qualitative attributes is also a simplification of the sensory evaluation process with the aim of not fatiguing the tasters but without losing important descriptive information about the wine.

The floral aroma family includes two main types of flowers: "white flowers" and "sweet flowers". These two categories include specific floral aromas (i.e., lily, violet, which would be "sweet flowers"). In our

Table 2
Other attributes selected and definitions, associated terms (synonyms), PDO and type of wine that is described in the technical specifications.

Attribute	Definition	Associated terms, PDO and wine type
Mineral	Odour reminiscent of geological elements such as gravel, granite, sand, clay, fresh cement, graphite, etc. (Qualitative assessment)	Fresh mineral notes: a19, a20, d1, d7, d13, i13
Alcoholic notes	Term describing the olfactory sensation caused by alcohol content. Only applicable to sweet wines, fortified wines and liqueur wines. (Qualitative assessment)	Well-integrated alcohol: a21, b21, c21, c22, g34, j26, j29, j30, j35, j32, j31
Aromatic persistence	Time that the olfactory sensation of wine lasts in the mouth, counted from the moment the wine is expelled or swallowed. Persistence is expressed in seconds or caudalies. Caudalie is the unit (seconds) of flavour duration (finish) in the mouth after swallowing or expectorating a wine (Jackson, 2017).A calibrated chronometer (Chronometer 419CA model, Instruments Horaires Moineau, France) is used.	Gustatory persistence: a(all wines), b16, c16, c21, c22, d(all wines), f27, h19, j4, j26, j29, j30, j35, j32, j31, k(all wines) Intense flavour: a1, e19, e22, e30 Aftertaste: i7, j7 Persistent in the mouth: a21, b21, d1, d7, d13, d19, e5, e6, e12, h19, j7 Long aftertaste: e29, f1, f13, f29 Middle distance: a1 Long-lasting finish: a13, e34, j24 Good palate aromas: f35, i7, j7

a: PDO Alella, b: PDO Catalunya, c: PDO Conca de Barberà, d: PDO Costers del Segre, e: PDO Empordà, f: PDO Montsant, g: PDO Penedès, h: PDO Pla de Bages, i: QPDO Priorat, j: PDO Tarragona, k: PDO Terra Alta,
1: White wine, 2: Young white wine, 3: Low alcoholic white wine, 4: Aged white wine, 5: White wine fermented in barrels, 6: White wine aged in wood barrels, 7: Rosé wine, 8: Young rosé wine, 9: Low alcoholic rosé wine, 10: Aged rosé wine, 11:Rosé wine fermented in barrels, 12: Rosé wine aged in wood barrels, 13: Red wine, 14: Young red wine, 15: Low alcoholic red wine, 16: Aged red wine, 17: Red wine fermented in barrels, 18: Red wine aged in wood barrels, 19: Quality sparkling wine, 20: *Vi d'agulla* (sparkling wine), 21: Liqueur wine/ fortified wine, 22: Natural sweet wine, 23: Sweet liqueur wine, 24*: Ranci* wine (Sherry stile wine), 25: Sweet *Ranci* (Sherry stile wine), 26*: Mistela* wine (fortified wine) 27: White *mistela* wine (fortified wine), 28: Red *mistela* wine (fortified wine), 29*: Garnatxa* wine (fortified wine from Grenache grape), 30*: Moscatell* wine (fortified wine from Muscat grape), 31*: Classic DO Tarragona* (fortified wine), 32*: Vi de missa* (Sacramental wine /fortified wine), 33: Sweet wine, 34: Late harvest wine, 35*: Vimblanc* (Sweet wine), 36*: Dolç de fred* (Ice wine), 37: *Vi de finca* (Single Vineyard Wines).

experience, the differentiation between different kinds of flowers (present in low intensity) is too complex for the extra information it provides. Only rose and jasmine were included as characteristic descriptors of some Tarragona PDO wines (Table 1). On the other hand, the lavender attribute was added to the family of aromatic herbs/forest herbs as characteristic of some wines from the PDO Pla de Bages (Table 1). The aromatic herbs attribute should not be confused with the vegetal aromas (Jackson, 2020) described as "green" (bell pepper, green beans), "herbaceous" (grassy, tea) or preserves (peas, asparagus, olives, artichoke) described by Noble et al. (1987). In the presented profile, the vegetal attribute is evaluated qualitatively and is clearly differentiated. Vegetal aroma can be considered an olfactory alteration of wines (OIV, 2016), and depending on their intensity, they may be considered varietal or an off odour (Jackson, 2017).

We differentiate fresh and dried fruit aroma families into two groups, adding a specific family for processed fruits and honey and considering that these attributes are present and even characteristic of certain types of wine. Our purpose was to characterize each wine by obtaining the intensity of the two attributes separately. For example, in fortified wines, the processed fruit families would be more intense, and in young wines, the fresh fruit would be more evident. Additionally, with the same purpose of taking into account all the characteristic attributes of each type and PDO, other new attributes, such as marmalade, syrup, quince, dried apricot, orange peel and "honeyed-silky", were added to this group, in addition to those described in the literature as the most common dried fruits (dried grapes, dried figs, dates).

The "Aging aromas" family, such as woody, nuts, roasted, empyreumatic and aged, were included in the same group to assess a joint intensity (characteristic of a specific wine type) and most of the descriptors (oaky, vanilla, smoky, toasty, almond, hazelnut, walnut, aged)

Table 3
Compounds and concentrations selected from the stock mixture and their corresponding intensity in the sensory scoring scale (in brackets).

Quantitative attribute or family	Stock mixture [C]	Selected concentrations
Floral	0.075 ml/L Rose aroma (Laffort España, Errenteria, Spain), 0.025 ml/L Jasmine aroma (Sosa, Navarcles, Spain), 0.0150 ml/L Orange blossom aroma (Sosa, Navarcles, Spain), 1 ml Violet aroma (Laffort España, Errenteria, Spain)	[C]/8 **(3)**, [C]/4 **(7)**, [C] **(10)**
Aromatic herbs and balsamic	0.2 ml/L Eucalyptus aroma (Sosa, Navarcles, Spain), 0.05 ml/L Mediterranean forest aroma (Sosa, Navarcles, Spain), 0.02 ml/L Fennel aroma (Sosa, Navarcles, Spain), 0.5 ml/L spicy maceration (0.23 g five pepper mix, 0.3 g clove, 0.15 g dry bay leaf, 0.3 g grated nutmeg, all macerated in 125 ml alcohol during a week), 14 ml/L liquorice root maceration (25 g of root liquorice (Montsant, Spain) cut into small pieces into 125 ml of alcohol to 5 days at 1 week)	[C]/16 **(3)**, [C]/8 **(5)**, [C]/4 **(7)**, [C]/2 **(9)**
Fruity	0.26 ml/L Pear aroma (Laffort España, Errenteria, Spain), 0.26 ml/L Apple aroma (Laffort España, Errenteria, Spain), 0.226 ml/L Wild strawberry aroma (Laffort España, Errenteria, Spain), 0.100 ml/L Vineyard peach (Absolute Arom, Barcelona, Spain), 0.120 ml/L Grapefruit aroma (Laffort España, Errenteria, Spain), 0.05 ml/L Orange extract aroma (Laffort España, Errenteria, Spain)	[C]/8 **(2)**, [C]/4 **(6)**, [C] **(9)**
Aging	37.5 ml/L of solution (75 g Nobile Intense oak wood chips (Laffort España, Errenteria, Spain), macerated in 250 ml alcohol during 5 days), 84,4 ml/L vanilla macerated solution (11 g vanilla in 250 ml alcohol during 5 days), 3,125 ml of solution of 0.23 g five pepper mix, 0.3 g clove, 0.15 g bay leaf, 0.3 g grated nutmeg, all macerated in 125 ml alcohol for 1 week)	[C]/8 **(4)**, [C]/4 **(6)**, [C] **(9)**
Lactic and post-fermentation	7 g/L Yogurt aroma (Lucta, Montornès del Vallès, Spain), 0.025 ml/L Bread crumb aroma (Sosa, Navarcles, Spain), 0.070 ml/L toasted hazelnut aroma (Sosa, Navarcles, Spain), 7 ml /L of freeze-dried yeast prepared "*in situ*" by adding 10 g of dried yeast (Zymaflore Laffort España, Errenteria, Spain) into 100 ml of water at 37 °C and stirring during 5–10 min with a glass shingle.	[C]/64 **(3)**, [C]/16 **(6)**, [C]/4 **(8)**,
Processed fruit, over-mature fruit and honey	60 g strawberry jam (Helios, Valladolid, Spain), 84 g quince jelly (Helios, Valladolid, Spain), 8 ml Fig syrup (Concentrados Palleja, S.L., Tarragona, Spain) macerated in 1 L of synthetic wine (SW) for a 1 week	[C]/4 **(3)**, [C]/2 **(6)**, [C] **(8)**,

All components were added to synthetic wine (Gomis-Bellmunt et al., 2022). All macerations have been carried out during five days at room temperature, in flasks of brown glass covered in screwcap and in absence of natural light. The alcohol used was ethanol 96.42%v/v (Alcoholes Monplet SA, Barcelona, Spain).

Table 4
Compounds or products, concentrations selected and amount provided to each taster as a reference to illustrate each qualitative sensory attribute.

Qualitative attribute	Compounds	Concentration	Amount per person
Sweet flowers	Rose aroma extract 10 % (Laffort España, Errenteria, Spain)	2 ml /L	50 ml
	Jasmine aroma (Sosa, Navarcles, Spain)	0.1 ml/L	
White flowers	Orange blossom(Sosa, Navarcles, Spain)	0.1 ml/L	50 ml
Rose	Rose aroma extract 10 % (Laffort España, Errenteria, Spain)	1 ml/L	50 ml
Jasmine	Jasmine aroma (Sosa, Navarcles, Spain)	0.2 ml/L	50 ml
Aniseed notes	Fennel aroma (Sosa, Navarcles, Spain)	0.1 ml/L	50 ml
Spicy	Masceration of 0.23 g five pepper mix, 0.3 g clove, 0.15 g bay leaf, 0.3 g grated nutmeg, all into 125 ml alcohol during a week	125 ml/L	50 ml
Lavender	Lavender aroma (Sosa, Navarcles, Spain)	0.4 ml/L	50 ml
Eucalyptus	Eucalyptus aroma (Sosa, Navarcles, Spain)	1 ml/L	50 ml
Mint	Green mint aroma (Sosa, Navarcles, Spain)	0.6 ml/L	50 ml
Liquorice (root)	Masceration of 25 g liquorice root into 125 ml alcohol between 5 days and 1 week	125 ml/L	50 ml
Red berries	Wild strawberry aroma (Laffort España, Errenteria, Spain) and	0.3 ml/L	50 ml
	Cherry aroma (Laffort España, Errenteria, Spain)	20 ml/L	
Strawberry	Wild strawberry aroma (Laffort España, Errenteria, Spain)	0.2 ml/L	50 ml
Cherry	Cherry aroma (Laffort España, Errenteria, Spain)	10 ml/L	50 ml
Forest berries	Blackberry aroma (Laffort España, Errenteria, Spain)	0.2 ml/L	50 ml
White tree fruit	Apple aroma (Laffort España, Errenteria, Spain) and	0.2 ml/L	50 ml
	Pear aroma (Laffort España, Errenteria, Spain)	0.2 ml/L	
Acid fruit/citric tones/ lemon	Lemon juice aroma (Sosa, Navarcles, Spain)	0.1 ml/L	50 ml
	Orange aroma (Laffort España, Errenteria, Spain)	0.1 ml/L	
Tropical fruit	Pineapple aroma (Laffort España, Errenteria, Spain) and	0.2 ml/L	50 ml
	Passion fruit aroma (Laffort España, Errenteria, Spain) and	0.075 ml/L	
	Litchi aroma (Laffort España, Errenteria, Spain)	0.1 ml/L	
Peach	Vineyard peach aroma (Absolute Arom, Barcelona, Spain)	0.2 ml/L	50 ml
Vanilla	Maceration of 5 g bourbon vanilla pods (Rapunzel Naturkost GmbH, Germany) in 250 ml alcohol for 5 days	125 ml/L	50 ml
Wood/ barrel tones	Maceration of 75 g American oak wood chips (Nobile American Blend ®, Laffort España, Errenteria, Spain) into 125 ml alcohol for 5 days	125 ml/L	50 ml
Smoked/ empyreumatic/ toasted	Maceration of 75 g French oak wood chips (Nobile Intense ®, Laffort España, Errenteria, Spain) into 125 ml alcohol for 5 days	125 ml/L	50 ml
Aldehydes/ ethanal	Acetaldehyde 99 % extra pure (Acros organics, Geel, Belgium)	0.6 ml/L	50 ml
Black liquorice	Black liquorice aroma (Sosa, Navarcles, Spain)	0.8 ml/L	50 ml
Nuts/ toasted nuts	Hazelnut toasted aroma (Sosa, Navarcles, Spain)	0.2 ml/L	50 ml
Hazelnut	Hazelnut aroma (Sosa, Navarcles, Spain)	0.3 ml/L	50 ml
Pastry	Biscuit aroma (Dallant, Sant Feliu de Llobregat, Spain) and	0.4 ml/L	50 ml
	Butter aroma (Dallant, Sant Feliu de Llobregat, Spain)	0.2 ml/L	
Bread notes	Bread crumb aroma (Sosa, Navarcles, Spain)	0.2 ml/L	50 ml
Lactic	Milk aroma (Lucta, Montornès del Vallès, Spain) and	0.074 ml/L	50 ml
	Yogurt aroma (Lucta, Montornès del Vallès, Spain)	2 g/L	
Wine lees (aging on lees)	A E Nat wine lees aroma (Laffort España, Errenteria, Spain)	0.075 ml/L	50 ml
Jam/ marmalade	Strawberry jam (Helios, Valladolid, Spain)		15 g
Grape jelly	Fig syrup (Concentrados Pallejà S.A., Tarragona, Spain)		15 g
Syrup	Rectified concentrated must, RCM (Concentrados Pallejà S.A., Spain)		40 ml
Quince jelly	Quince jelly cream in portions (Helios, Valladolid, Spain)		21 g
Fig fruit	Dried figs (in bulk, La Balança, Vilafranca del Penedés, Spain)		15 g
Raisin	Sultana Raisins (in bulk, La Balança, Vilafranca del Penedés, Spain)		15 g
Dried apricot	Dried apricot aroma (Lucta, Montornès del Vallès, Spain)	0.15 ml/L	50 ml
Dried dates	Dried dates (in bulk, La Balança, Vilafranca del Penedés, Spain)		15 g
Orange peel	Orange soluble aroma (Dallant, Sant Feliu de Llobregat, Spain)	0.2 ml/l	50 ml
Melon	Cantalup melon aroma (Sosa, Navarcles, Spain)	0.1 ml/l	50 ml
Grape	Must, Xarel·lo variety (Llopart, Spain)		50 ml
Mellow/ honeyed	Honey aroma (Sosa, Navarcles, Spain) and	0.2 ml/L	50 ml
	Moscatel essence (Absolute Arom, Barcelona, Spain)	0.1 ml/L	
Mineral	Mineral mix (Zaldívar Santamaría et al., 2019)	1 ml/L	50 ml
Alcoholic notes	Ethanol 96,42 %v/v (Alcoholes Monplet SA, Barcelona, Spain)	10.3 ml/L	50 ml

All components were added to synthetic wine (Gomis-Bellmunt et al., 2022). All macerations have been carried out during five days at room temperature, in flasks of brown glass covered in screwcap and in absence of natural light. The alcohol used was ethanol 96.42%v/v (Alcoholes Monplet SA, Barcelona, Spain).

are included at a qualitative level.

According to the OIV review (OIV, 2016), some aromas classified as woody/phenolic/leather are considered an alteration if only present in high concentrations in wines, coinciding with the perception of most consumers (Francis & Williamson, 2015). In our case, they have been defined as volatile phenols/Brett and are evaluated qualitatively. The acetaldehyde/ethanal attribute was included in the "aging aromas" family and was differentiated from the oxidation attribute. Acetaldehyde is associated with an oxidative carrier. There are types of wines (vi ranci, vi de missa, or Xerez/Sherry wine) where the olfactory presence of ethanal/oxidation is typical and is the result of aging (OIV, 2016). In the rest of the wines, it implies a loss of freshness and an olfactory alteration that some authors characterize as cooked vegetable, boiled potato, cardboard, pungent, spicy (Jackson, 2020).

The postfermentation and lactic aroma family refers to aromas of microbiological origin described in the literature (Jackson, 2020). We also added specific aromas such as pastry or bread notes, characteristic of some types of wine from the Pla de Bages, Priorat and Montsant PDOs (Table 1). This family has been included in the profile to cover the importance of aromas produced by yeasts, mainly due to secondary metabolites (fermentative and postfermentative aromas) or to the autolytic degradation of dead yeast cells (Capece & Romano, 2019). This family is associated with lactic, buttery, backed or yeasty aromas generally considered desirable (Jackson, 2017). In fact, although in the

Table 5
Compounds and selected concentrations as representatives of the different alterations/off-odours of wine.

Attribute	Compound	Concentration
Reduction 1	Ethanethiol, 97 % (Fluka Chemie GmbH, Buchs, Switzerland)	0.006 ml/L
Reduction 2	Methionol (Dolmar, Gimileo, Spain)	6 ml/L
Reduction 3	Hydrogen sulfide (Dolmar, Gimileo, Spain)	20–50 mg/L aprox
Oxidation 1	Acetaldehyde 99 % extra pure (Acros organics, Geel, Belgium)	100 mg/L
Oxidation 2	Soloton (Dolmar, Gimileo, Spain)	0.035 ml/L
Volatile acidity 1	Acetic acid 96 % (Merck, Darmstadt, Germany)	0.75 g/L
Volatile acidity 2	Ethyl acetate (Dolmar, Gimileo, Spain)	250 mg/L
Volatile Anisoles 1	2,4,6-Trichloroanisole (Dolmar, Gimileo, Spain)	11 ng/L
Volatile Anisoles 2	2,4,6-Tribromoanisole (Dolmar, Gimileo, Spain)	20 ng/L
Volatile phenols (Brett)	4-Ethylphenol and 4-Ethylguayacol (Dolmar, Gimileo, Spain)	0.5 mg/L and 0.2 mg/L
Vegetable 1	IBMP (3-Isobutyl-2-methoxypyrazine) (Dolmar, Gimileo, Spain)	80 ng/L
Vegetable 2	1-Hexenol (Dolmar, Gimileo, Spain)	15 mg/L
Moldy/earthy	Geosmina (Dolmar, Gimileo, Spain)	200 ng/L

All compounds were added to synthetic wine (Gomis-Bellmunt et al., 2022).

OIV review (OIV, 2016), it is considered one of the main alterations of wine, the same document states that many consumers express a preference for wines exhibiting a buttery character resulting from the production of diacetyl during malolactic fermentation.

Finally, the qualitative attributes mineral and alcoholic notes have also been included in the profile. Minerality and alcoholic notes were difficult to categorize in one of the above families, as their characteristics do not resemble any of them. The attribute minerality in wine is highly fashionable, but it is unclear what it involves (Parr et al., 2018). Recent studies conclude that the perception of mineral character in wine is an extremely complex issue and does not depend on a single chemical compound (Parr et al., 2018; Zaldívar Santamaría et al., 2019). In our case, it was decided to include it in the profile since the mineral attribute characterizes the white, rosé and red wines of the Costers del Segre PDO, the red wine of the Priorat PDO and the sparkling wine of the Alella PDO (Table 2).

In the PDO technical specifications, reference is made to the expression “absence of off-odours”. To indicate the absence of defects, qualitative attributes associated with alterations have been considered. This term presents a growing controversy between what should be considered a “glaring defect or alteration” and what must be considered the result of “established expertise” or the typicality of a grape variety (OIV, 2016). In the method developed, only the presence (or absence) of the attributes susceptible to common alterations in wines should be tested. This option allows subsequently checking whether it is appropriate to the wine type or whether it is an alteration.

4.2. Reference standards development

Harmonization of the terminology used to describe sensory characteristics is just as important as harmonization of the references to be used in the sensory evaluation of food products and wines (Pérez-Elortondo & Zannoni, 2021). As Jackson (2020) notes, preparing, maintaining, and standardizing olfactory references is not easy. Until now, for sensory analysis of a wine, each panel chooses the sensory references that seem most appropriate from the numerous published options. There are works where pure products were used as references (Noble et al., 1987, Zoecklein et al., 2001, Carlucci & Monteleone, 2008, King & Heymann, 2014, Jackson, 2017). Other options available on the market are commercial kits with chemical compounds encapsulated or presented on inert blotting paper in special wide-collar vials (Le nez du vin ®, Cassis, France or Robertet, Grasse, France), which are also used by some authors (Vannier et al., 1999; Garcia-Carpintero et al., 2011; Ballester et al., 2013). Third, there are works that define and characterize aromas attributed to chemical compounds in wine (Guth, 1997,1998; Ferreira et al., 2000, 2002; Francis & Newton, 2005; Polaskova et al., 2008; Sherman et al., 2017). In the present paper, nineteen quantitative references (three or four intensity points for each olfactory family) and fifty references for each of the qualitative attributes were developed and validated to facilitate the implementation of the profile obtained.

The decision to use preferentially commercial flavourings was based on the easiness of preparation, reproducibility and the possibility of choosing from a wide range of synthesized flavourings available on the market. In the same vein of reproducibility of the references, a synthetic wine matrix was used, which allows us to reproduce the references independently of the wine used. The use of a wine matrix, as used by some authors (Zoecklein et al., 2001; Hidalgo, 2011), when working with different wine types, as in our case, is not appropriate since each wine type and vintage presents a variable aromatic background and would add a nonreproducible variability. Using synthetic wine also guarantees the noninterference of other compounds in the wine matrix, which could alter olfactory perception. The volatility of wine aroma molecules could be influenced by the presence of other constituents (sugars, ethanol, oils, polyphenolics and other macromolecules such as proteins) present in the wine matrix (Delwiche, 2004; Francis & Newton, 2005; Jackson, 2020).

From an economic and practical point of view, an interesting factor to consider is the durability and stability of the reference elaborated with hydroalcoholic solutions versus the wine matrix. Wine matrices have a reduced durability due to the constant evolution of the wine itself, so this type of reference can be used reliably in short periods of time and should be prepared again at each training.

The references have been developed only for the olfactory phase, which implies that tasters should integrate the sensations of direct olfaction and retronasal (flavour) to assess the different samples. This limitation is justified in view of the large number of references required and the complexity involved if separate references were to be developed for both types of olfaction.

4.2.1. Quantitative reference standards

One of the improvements presented in this work is the development of global standard references for six descriptors of aromatic families, proposing multicomponent mixtures for each descriptor and their quantification as a quantitative attribute in at least three intensity points (at least one low, one medium and one high point) (Table 3). The need to develop global standard references (i.e., family floral, family fruity) was justified by the fact that most PDO technical specifications mention families to describe a wine type instead of using specific attributes (Table 1).

The reference for the floral attribute includes a mixture of aromatic extracts from several flowers (rose, jasmine, orange blossom and violet). Other authors (King & Heymann, 2014 King et al., 2013 Zoecklein et al., 2001, Etaio et al., 2010) use only one or two compounds, such as linalool, geraniol, benzyl acetate or orange blossom extract, to represent the floral descriptor. In our opinion, using a single compound to represent the full range of this attribute in wines may be incomplete, as it only provides information on one type of flower. In the same vein, to

represent the fruity attribute, a mixture of natural extracts of pear, apple, strawberry, peach, grapefruit and orange was used to achieve the widest possible global perception of the descriptor. In the literature, only one fruit has been used to represent the global family, i.e., peach and apricot (Zoecklein et al., 2001) or lemon essential oils at different concentrations (Kitamoto et al., 2018).

The remaining four quantitative families are reported for the first time in this paper. The elaboration of these references was quite complex to achieve adequate attribute suitability, as commercial aromas were combined with alcoholic macerations.

4.2.2. Qualitative reference standards

In the literature (Meilgaard et al., 1982, Noble et al., 1987, McDaniel et al., 1987, Zoecklein et al., 2001, Carlucci and Monteleone, 2008, Hidalgo, 2011, Ballester et al., 2013, Jackson, 2017, 2020), there is a wide variety and type of products used as reference standards for qualitative attributes. The pioneer Ann Noble (references adopted by the American Society for Enology and Viticulture) listed a wide variety of references, mostly based on natural products, such as pressed orange blossom as a reference for orange blossom, preparations of natural elements, and chemical compounds such as 2-phenylethanol as a reference for rose aroma.

Most of the qualitative references presented in this work (Table 4) are based on commercial flavourings, the only exceptions being cases where the tested products were not sufficiently suitable. This is the case for the references for the spicy, liquorice root, vanilla, woody/barrel tones and smoked/empyreumatic/toasted descriptors, where alcoholic macerations were presented with natural products. Moreover, references for the attributes of the processed fruit family were the most difficult to reproduce with commercial aroma extracts. None of the products tested suited the type of aroma perceived in the wine. Most of the references used natural products directly. This is the case for the use of jam/marmalade, dried figs, raisins or dried dates, in accordance with Noble et al. (1987) and Ballester et al. (2013). In the same family, the descriptors grape jelly, syrup, quince jelly and honeyed/silky were developed by our group, which have not yet been described or used by any author. To represent the descriptors quince and syrup, the use of natural products was the most appropriate. For the syrup, it was decided to use "rectified concentrated must", as the syrup (water and sugar) did not give the desired olfactive sensation and the fruit in the syrup gives the flavour of the fruit it contains.

The minerality descriptor was undoubtedly the most difficult to reference. After testing numerous products, such as stones, clays, gypsum, water with high minerality and others, the expected olfactory perception was not found. The difficulty in finding a suitable reference is related to the lack of consensus on the term minerality (Ballester et al., 2013, Rodrigues et al., 2017, Parr et al., 2018, Zaldívar Santamaría et al., 2019), although they seem to agree that minerality does not depend on a single compound. According to Rodrigues et al. (2017), minerality could be related to sensory descriptors such as reductive notes, sulphur, cabbage, cardboard, flinty/smoky, chalky/calcareous, wet stone, citrus, fresh and shellfish. Another recent study by Zaldívar Santamaría et al. (2022) associates minerality with flint, slate, pencil lead, rock, earthiness, and chalk. Therefore, due to the lack of consensus, it was decided to use the reference of minerality developed by Zaldívar Santamaría et al. (2019).

The reference for the alcoholic note descriptor was developed using a hydroalcoholic solution with a higher alcohol content than the synthetic wine (matrix) so that the taster could perceive more warmth due to the alcohol concentration, in line with Noble et al. (1987), who suggest a concentration of up to 40 % v/v.

The validation process of the references showed that the references not only agreed upon by the tasters but also proved to be suitable for assessing a large range of real wines.

4.3. Application of the profile and references developed

One of the applications of the olfactive descriptive profile and references developed is the training and implementation of a sensory panel for the control of PDO wines. The objective of sensory control of PDO wines is to guarantee the product to the final consumer (OJEU, 2013). This "guarantee" of the product is related to factors provided by sensory characterisation such as wine distinctiveness (typicity) and quality (Souza Gonzaga et al., 2021). As global multidimensional sensory concept, authors agree on the holistic way to explore the typicity degree of wines, via one single question with a panel of wine industry expert/professionals (Souza Gonzaga et al., 2021), method elucidated by Ballester (Ballester et al., 2005). Although professionals often agree on typicity of grape varieties, the sensory spaces of several closes PDO often overlap and make the task difficult for professionals to get an agreement on PDO (Maitre et al., 2010). This approach and others that do not describe the products are unsatisfactory for the systematic sensory control of PDO products because the European regulation (OJEU, 2013) requires applying objective and homogeneous sensory methods to reach an organoleptic description of the product that allows evaluating their conformity with the technical specifications.

Currently, accredited sensory control methods applied to evaluate the conformity of PDO products go beyond the identification of defects or the quantification of quality/typicity by holistic way on a single scale. Recently, Pérez-Elortondo & Zannoni (2021) provided generic guidelines for the sensory analysis of PDO food products, including examples of different approaches, criteria, and recommendations. these methods differ in the nature of the scores obtained on the scales of the sensory evaluation scorecard: *compliance score (degree of conformity or trueness to type)* or *citation frequency/intensity of sensory attributes.*

In the case of methods focused to *score the degree of conformity (trueness to type),* the sensory panel verify the "quality or degree of compliance" of the wine to pre-established sensory standard categories (one for each type of wine). This is the case proposed by Etaio et al., (2010, 2012) for specific type of wines, such as young red wine from the Rioja Alavesa or for Txakoli. However, to evaluate the conformity to a wide variety of wine types and origins (as is the case for the 11 PDOs presented), this approach would be unsolvable, and a method focused to *citation frequency/intensity of sensory attributes* is more effective. This is the approach considered in this work. In both approaches, the statement of conformity consists of evaluating for each sample of wine, the limits of conformity stablished by the PDO: in the first case, the conformity degree scores and in the second case the intensity scores and/or presence or absence of certain attributes for each descriptor.

The methodology proposed (by application of the profile and references) allows the analysis of a wide range of wine if all of the proposed descriptors (6 quantitative and 50 qualitative descriptors) are taken into account. The result obtained from the sensory analysis permits subsequent verification against almost any technical specifications (each PDO can apply their own requirements) and also the characterization of wines affected by other factors such as variety, harvest or origin.

In the specific case of product verification or conformity, the process would consist of checking the results obtained from the sensory analysis in relation to the requirements of the corresponding type of wine specified by each PDO. To declare the conformity or non-conformity of the product, it is necessary to establish the evaluation criteria in accordance with the technical specifications. The document containing the assessment criteria must be approved (e.g., by the PDO "Conformity Assessment Body/ Control Body") or published by the competent authority (EA, 2022). The statement of conformity, issued by the competent entity (i.e. conformity assessment body, PDO regulatory board or laboratory

Table 6
Example of analytical results obtained in the sensory evaluation of 3 types of wines from 3 different PDO's. First column of each PDO/type shows the results from the sensory method and the second column indicates whether the descriptors is included or not in the corresponding specifications.

ORIGIN:		PDO Empordà		PDO Priorat		PDO Pla de Bages	
WINE TYPE:		Garnatxa wine		Red wine aged in wood barrels		Rosé wine	
		Sensory result	Included in specifications? ***	Sensory result	Included in specifications? ***	Sensory result	Included in specifications? ***
Quantitative attributes*	Floral	6.5	No	**2.8**	**Yes**	5.1	**No**
	Aromatic and forest herbs/ balsamic	4.8	No	**4.1**	**Yes**	**4.7**	**Yes**
	Fruity	**7.3**	**Yes**	**4.6**	**Yes**	**5.4**	**Yes**
	Aging	1.5	No	**6.8**	**Yes**	1.1	No
	Lactic and post-fermentation	2.4	No	**2.9**	**Yes**	**2.0**	**Yes**
	Processed fruit and over-mature fruit and honey	**6.9**	**Yes**	**3.3**	**Yes**	2.4	No
Qualitative attributes**	White flower	89 %	No	**3 %**	**Yes**	97 %	No
	Sweet flower	97 %	No	**100 %**	**Yes**	89 %	No
	Rose	22 %	No	3 %	No	22 %	No
	Jasmine	22 %	No	3 %	No	3 %	No
	Aniseed notes	73 %	No	22 %	No	**100 %**	**Yes**
	Spicy	89 %	No	**100 %**	**Yes**	97 %	No
	Lavender	78 %	No	11 %	No	100 %	No
	Eucalyptus	73 %	No	89 %	No	73 %	No
	Mint	73 %	No	0 %	No	3 %	No
	Liquorice (root)	11 %	No	22 %	No	0 %	No
	Red fruits	3 %	No	**100 %**	**Yes**	**100 %**	**Yes**
	Strawberry	0 %	No	**3 %**	**Yes**	73 %	No
	Cherry	0 %	No	89 %	No	22 %	No
	Black fruits	3 %	No	100 %	No	3 %	No
	White fruit	100 %	No	**0 %**	**Yes**	89 %	No
	Acid/citrus fruit	97 %	No	**0 %**	**Yes**	100 %	No
	Tropical fruit	97 %	No	0 %	No	11 %	No
	Peach	97 %	No	0 %	No	3 %	No
	Vanilla	3 %	No	100 %	No	0 %	No
	Wood/ barrel tones	11 %	No	**100 %**	**Yes**	0 %	No
	Empyreumatic	3 %	No	100 %	No	0 %	No
	Aldehydes	3 %	No	3 %	No	3 %	No
	Liquorice (candy)	3 %	No	100 %	No	3 %	No
	Nuts	73 %	No	97 %	No	73 %	No
	Hazelnuts	3 %	No	11 %	No	0 %	No
	Pastry/ confectionery	22 %	No	73 %	No	**0 %**	**Yes**
	Bread notes	0 %	No	3 %	No	0 %	No
	Lactic	22 %	No	**100 %**	**Yes**	73 %	No
	Lees	11 %	No	11 %	No	97 %	No
	Jam/marmalade	100 %	No	100 %	No	100 %	No
	Grape jelly	3 %	No	11 %	No	0 %	No
	Syrup	97 %	No	11 %	No	3 %	No
	Quince jelly	89 %	No	22 %	No	22 %	No
	Grape jelly	11 %	No	97 %	No	0 %	No
	Raisin	78 %	No	78 %	No	3 %	No
	Dried apricot	100 %	No	3 %	No	3 %	No
	Dried dates	11 %	No	22 %	No	0 %	No
	Orange peel	89 %	No	22 %	No	78 %	No
	Melon	89 %	No	0 %	No	3 %	No
	Grape	78 %	No	0 %	No	3 %	No
	Mellow/silky & honey	**97 %**	**Yes**	3 %	No	0 %	No
	Mineral	3 %	No	0 %	No	0 %	No

* Quantitative attributes have been calculated by averaging the individual scores of the tasters on a scale of zero to ten points. ** For the qualitative attributes. Tasters have to mark "yes/no" on the tasting sheet. In this case the result is calculated as the probability of presence (%) taking into account a binomial distribution ($\alpha = 0.05$, $n = 8$). *** The conformity limits are established by each PDO.

accredited (ISO, 2017b) for this purpose), must indicate the document containing the assessment criteria, its revision status and/or date of approval and also the technical specifications of the PDO to which it refers.

Table 6 shows an example of the application of the method (accredited according to ISO 17025 (ISO, 2017b), showing the result obtained from the sensory analysis of a wine sample in a session with 8 panellists. The application of this method provides results for all parameters included in the profile. However, not all the parameters provided are required in the specifications of a certain PDO. The descriptors required by type/PDO are marked as an example. The minimum limits of each parameter for assessing product conformity must be decided by the competent body of each PDO.

5. Conclusions

This work contributes to the development of a harmonized sensory profile with corresponding references for the sensory attributes covered, which in wine are currently nonexistent at the international level. This tool can be used for official control of PDO wines. Specifically, an

aromatic wheel for PDO Catalan wines has been created, which was also nonexistent until now, but the descriptive profile developed for 37 wine types is applicable to other PDOs, as they usually include attributes and terms such as those described in this paper. Additionally, references developed can be useful when creating similar panels. The information provided in the present paper can be used for other applications, such as the characterization of wine types, grape varieties, and different production areas, or can even help winemakers achieve internal control. The method has been applied within the Catalan Institute of Vine and Wine (INCAVI) accreditation scope according to ISO 17025 (ISO, 2017b) since 2019.

Ethical statements

The study was approved by the Ethical Committee of the Institute of Agrifood Research and Technology (IRTA), registration number CCSC 23/2022, in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

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CRediT authorship contribution statement

Anna Gomis-Bellmunt: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Resources, Project administration, Funding acquisition. **Anna Claret:** Methodology & Writing – review. **Luis Guerrero:** Conceptualization, Methodology, Formal analysis, Supervision & editing. **Francisco José Pérez-Elortondo:** Conceptualization, Supervision, Writing – review & editing. All authors have read and agreed to the published version of the manuscript.

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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Appendix A. Supplementary data

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