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Feasibility of Using Secondary Attributes in Sensory Analysis to Characterize Protected Designation of Origin of Olive Oil

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Abstract: Protected denomination of origin (PDO) designations require tools to enable differentiation, as each PDO aims to establish its own distinct and exclusive identity. This necessity becomes particularly challenging in those regions where PDO territories are very close to each other, as is the situation with the extra virgin olive oil (EVOO) PDOs in Catalonia. The proximity of these territories can make it difficult to perceive the uniqueness of each area solely on the basis of the evaluation of a few general sensory descriptors. This study examines whether the frequency of use of different secondary attributes, established by the Official Tasting Panel of Virgin Olive Oils of Catalonia, can effectively differentiate PDOs. Thus, a total of 1330 EVOOs from the five Catalan PDOs, produced during the 2012–2020 period, have been analyzed by the Official Tasting Panel of Virgin Olive Oils of Catalonia. The results of the statistical analysis, using this historical database of samples, show that the frequency of the attributes does not occur randomly, but is significantly influenced by the production area and the olive cultivars associated with each PDO. These findings highlight the importance of incorporating specific secondary descriptors into the bidding specifications of PDOs, which can be a useful discriminant tool.

Keywords: Catalan PDOs; quality; secondary attributes; sensory analysis; extra virgin olive oil

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1. Introduction

According to the regulations, to classify an olive oil within the different categories, it is necessary to define both its physicochemical properties, as well as its organoleptic characteristics [1]. However, the information provided by sensory analysis goes beyond simple classification, since the small sensory differences detected in each oil can provide distinctive value to extra virgin olive oil (EVOO) produced all over the world [2].

This distinction is related to the EVOO aroma and taste [3]. The taste is due to polyphenols [4], whereas the aroma is composed of a complex set of so-called 'odorants'. These are volatile chemical compounds that may belong to very different chemical families, but share a common property in being able to interact with the receptors in the human nose when they exceed a specific concentration (perception threshold). Most of these odorants are the same in whichever EVOO is being considered, which means that the sensory differences among such products are due to small differences in the concentration level and/or the presence/absence of a few of these aroma compounds [5]. It should be noted that olive oils only differ from each other in terms of a narrow range of 2% regarding their minority composition and this percentage becomes even smaller if only those compounds evaluated in the sensory analysis (those related to aroma and flavor) are considered [6].

The importance of these small differences on the quality of olive oil has led different competent organizations to promote certain characteristics. Thus, the European olive oil protected denomination of origin (PDO) system aims to recognize high-quality oils produced in particular regions, where the climatic conditions, geographical environment, and cultivars provide characteristic EVOOs that must be preserved [7]. In these cases, apart from the official descriptors, which must be evaluated according to the regulation in order to categorize the olive oil as an EVOO [8], a complementary set of descriptors is also necessary to define PDO olive oils [9,10].

Throughout the Mediterranean region, the birthplace of olive oil, there are about 100 PDOs, Italy stands out with 43 and Spain with 27 [11]. Five of the latter are found in Catalonia, a small region located in the northeast part of Spain, with a long olive-growing tradition. These PDOs are Empordà (E) [12], Les Garrigues (LG) [13], Siurana (S) [14], Terra Alta (TA) [15], and Baix Ebre–Montsià (BEM) [16]. Among these PDOs, Siurana and Les Garrigues are the largest EVOO producers, with amounts ranging between 4000–7000 and 1000–5000 tonnes/year, respectively. The production by the other three Catalan PDOs is usually lower than 300 tonnes/year [17].

The distinctive and differentiating feature of Catalan olive cultivars is their great diversity compared to other Mediterranean countries that have more regular plantations, and despite the fact that some of these regions have replaced their native varieties with more productive ones. Thus, although some Catalan production areas share some of the same varieties such as 'Arbequina' (E, LG, S, and TA), 'Morrut' (BEM, TA, and S), or 'Farga' (BEM and TA), there are varieties that are only grown in specific zones of Catalonia, such as 'Sevillenca' (BEM), 'Empeltre' (TA), 'Rojal' (S), 'Verdiell' (LG), 'Argudell', 'Curivell', and 'Llei de Cadaqués' (E) [17].

The diversity in terms of the climate, geographical features, and varieties makes each PDO unique, with the produce showcasing its own specific sensory attributes. For the Catalan PDOs, there is a set of specific sensory descriptors, which are categorized into two distinct groups: primary and secondary descriptors. The primary descriptors were fully established by the Official Tasting Panel of Virgin Olive Oils of Catalonia, and these are: 'green', 'astringent', 'sweet', 'almond', 'walnut', 'apple', and 'other ripe fruits'. Regarding the secondary descriptors, to date, they remain not as well-defined; although some PDO regulations specify particular aromas [9], the Official Tasting Panel of Virgin Olive Oils of Catalonia allows tasters to freely determine these attributes. Thus, although secondary descriptors show great potential for differentiating PDOs, they remain unstandardized. This standardization could only be achieved through the sensory evaluation of a sufficiently large and representative sample dataset from each PDO, ensuring the reliability of the results obtained.

At this point, it is worth highlighting that the Institute of Agrifood Research and Technology of Catalonia (IRTA) has been working for approximately 20 years on a 'Quality Improvement Program of the Catalan Olive Growing Areas', which includes an expanded sensory description of commercial batches of olive oil produced in Catalonia [18]. Since this expanded sensory analysis involves the use of both primary and freely chosen secondary descriptors, we are faced with the possibility of achieving reliable results that highlight the significance and importance of these secondary descriptors in differentiating between PDOs.

Therefore, the aim of this study is to determine whether secondary descriptors are robust enough to be used as criteria for differentiating between PDOs, using the data on Catalan EVOOs as an example. In particular, the aim is to describe the sensory profile of Catalan EVOOs from an objective, scientific basis and to develop, through this mechanism, the particular sensory descriptors of the different PDOs [19]. Once this objective has been achieved, these attributes may be trainable in terms of the tasting panel and auditable using quality accreditation mechanisms. Furthermore, the selection of a specific set of aromatic descriptors will make it possible to study their chemical basis, in order to better under-

stand the cultivar–environment relationship that is the strategic basis for differentiating between PDOs.

2. Materials and Methods

2.1. Cultivars and Geographical Regions

The cultivars studied were those grown in the five Catalan PDOs: Empordà, Les Garrigues, Siurana, Terra Alta, and Baix Ebre–Montsià (Figure 1).

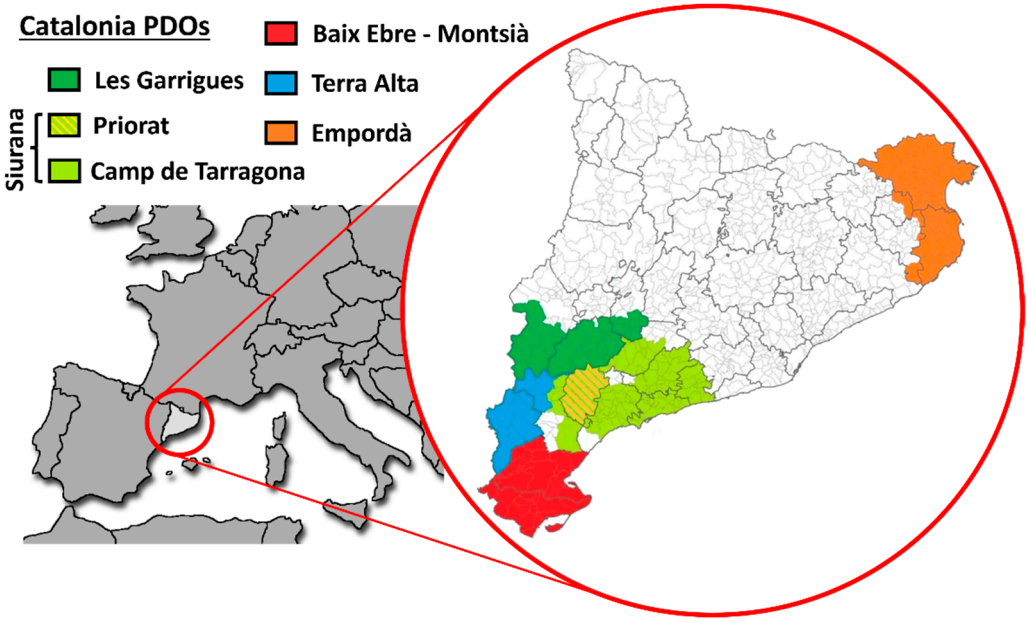

Figure 1. The location of the different PDOs in Catalonia.

The northernmost PDO in Catalonia is Empordà (E). The most characteristic climatic feature of this region is the strong north wind, the Tramontana. As for temperature, the winters are mild, with few frosts, and the summers are hot, tempered by sea breezes. The rainfall is around 600 L per year. This PDO boasts the native variety 'Argudell', in addition to the common variety 'Arbequina' [20].

The PDO in Les Garrigues (LG) is located in the central west of Catalonia, on the plane of Lleida, where the climate is characterized by low average annual precipitation (around 390 L per year), very cold winters, with persistent fog, and very hot summers [21]. The native varieties in this zone are 'Arbequina' (the most widespread Catalan variety) and 'Verdiell'. Regarding Arbequina, in addition to being cultivated in traditional orchards, in recent years the production process involving this variety has undergone a complete expansion in terms of a high-density cultivation system, thanks to the introduction of new irrigation infrastructure.

The largest PDO is Siurana (S), which comprises two geographical zones: Priorat (P), located in the mountains surrounding the PDO, and Camp of Tarragona (C), situated on the plains next to the Mediterranean Sea. The different altitude leads to differences in the climate, soil composition, and even secondary cultivated varieties. Thus, the olive orchards in the P zone are planted at altitudes between 300 to 800 m, in soils of Paleozoic origin, with low fertility (with transitions to tertiary sedimentary soils towards Les Garrigues), and exposed to a 'south pre-littoral Mediterranean' climate. On the other hand, in the C area, the olive groves are at zero-level elevation, planted in Quaternary sedimentary soils, and are exposed to a 'south littoral Mediterranean' climate [22]. Regarding the cultivated varieties, in addition to 'Arbequina' and 'Morrut' that are cultivated in both areas, the P zone cultivates the native variety 'Rojal' and the C zone cultivates the native variety 'Menya'.

The Terra Alta PDO (TA) is situated in the highlands of the Ebro River and its soils are calcareous, which, after deforestation, has resulted in reddish soils, with very low fertility, as a result of phosphorus blockage [23]. Due to its location, it is considered a transition region between the mountain climate zone and another zone with continental tendencies. In addition to the 'Arbequina', 'Farga', and 'Morrut' varieties, the native 'Empeltre' variety is also found in this PDO.

Finally, in the south of Catalonia, the Baix Ebre–Montsià PDO (BEM) is located, whose main geographical and climatic influence is the lower course of the Ebro River, in such a way that this zone experiences Mediterranean climatology. Its reddish soils, which occupy the cretaceous, calcareous crevices, together with the shallow, basal soils, with a high level of carbonate content from the Quaternary plains, host some of the oldest olive trees in the Iberian Peninsula [24]. The native variety in this area is 'Sevillenca'; although other varieties, such as 'Morrut' and 'Farga', are also grown here.

2.2. Samples

The samples used in the present study belong to the 2012–2020 period. Along with the 8 consecutive harvesting campaigns, sampling was carried out by IRTA technicians through 44 milling factories from the five Catalan PDOs, within the framework of the 'Quality Improvement Program of the Catalan Olive Growing Areas' launched by the Catalan Government [18]. Throughout the eight campaigns, each one lasting about three months, each mill was sampled once a week, which guarantees the representativeness of the analyzed samples over time. Furthermore, only full tanks were sampled, in order to have a representative view of the real samples delivered to the markets. Samples from the Siurana PDO were split according to its two subareas, Priorat and Camp de Tarragona. This division was carried out in order to verify a previous hypothesis, according to which the Priorat area is a transition zone between C and LG from a sensory point of view [25].

A total of 1330 EVOO samples were included in this study, as can be seen in Table 1: 160 from E, 572 from LG, 355 from P, 46 from C, 70 from TA, and 127 from BEM production areas. The sensory and analytical traits of the EVOOs are reviewed below.

Table 1. Number of EVOO samples per PDO and year. E: Empordà; LG: Les Garrigues; S: Siurana (P: Priorat; C: Camp of Tarragona); TA: Terra Alta; BEM: Baix Ebre–Montsià.

PDO	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
E	32	22	9	16	15	16	23	12	15	160
LG	41	45	48	71	63	63	61	67	113	572
S (P)	46	35	40	64	51	38	30	26	25	355
S (C)	—	—	—	—	—	—	6	21	19	46
TA	2	—	2	8	7	5	5	23	18	70
BEM	2	6	13	15	19	15	10	22	25	127

2.3. Sensory Analysis

Sensory analysis was carried out by the Official Tasting Panel of Virgin Olive Oils of Catalonia, certified by ISO 17025, since 2002, and recognized officially by the IOC and EU every year during that period. The official method of sensory analysis involves a minimum of 8 officially trained tasters, using a reglementary blue or red olive oil tasting glass, containing 15 mL of the sample at 28 ± 2 °C. Each taster evaluates the official attributes 'fruity', 'bitter', and 'pungent', together with the absence of organoleptic defects, according to the official regulation [8].

The samples that the sensory evaluators categorized as EVOOs were evaluated again in another tasting session, in order for the samples to be described in detail. To carry out this second evaluation, the tasters used the set of primary descriptors specifically defined for the Catalan PDOs, together with other secondary descriptors that could be freely chosen by each taster [9]. The primary attributes were evaluated in the same way as the official ones, that is, using an unstructured, continuous scale from 0 to 10 cm. The primary descriptors

used for evaluating EVOOs from Catalan PDOs are 'green', 'astringent', 'sweet', 'almond', 'walnut', 'apple', and 'other ripe fruits'. It should be noted that the attributes 'almond' and 'walnut' have only been considered primary descriptors since 2016. In addition to these attributes, 'complexity' and 'global score' values were also calculated. These are two calculations established by the Official Tasting Panel of Virgin Olive Oils of Catalonia [25]. Briefly, 'complexity' is the number of secondary descriptors perceived by at least 30% of the tasters and the 'global score' is a value between 0 and 9 related to the global sensory quality of the sample, as detailed in the initial EU Regulation 2568/91 (the extra virgin category rates over 6.5); this 'global score' is not provided by individual tasters, but the result of a mathematical calculation that is based on the median of the values given by the panel [26]. Finally, the tasters were free to annotate the secondary attributes as they saw fit. However, according to the general agreement existing in Catalonia, only those secondary descriptors perceived by at least 33% of the judges were considered and accepted [18].

During the years considered in this study, the panel was trained, at least once per year, in the specific use of each one of the primary descriptors used by the Catalan PDOs. Obviously, tasters are not informed about the nature of the samples they will be analyzing in a session.

2.4. Chemical Analysis

All the samples were chemically analyzed by the Official Laboratory of the Catalan Government, so the content of free fatty acids, the peroxide index, and the UV specific extinction coefficients K_{232} and K_{270} were determined using the official methods of analysis [27]. Values for these parameters that were not suitable and/or the presence of defective sensory descriptors were used to discard defective samples, which could not be classified within the extra virgin olive oil category.

2.5. Statistical Analysis

To study the data on the official and primary attributes of the EVOOs from among the PDOs, analysis of variance (ANOVA) was used. This allows the assessment of how different factors contribute to variability in terms of the sensory attributes. The factors considered in our analysis include the area (comprising the geographic zone and the variety–medium interaction), the campaign (accounting for variability related to the climatic conditions for each year), the harvest timing (i.e., the maturity state of the olives at harvest for each campaign), and the mill (which considers potential differences in the extraction process at each production facility). By using ANOVA, we can determine the significance of each factor and their interactions in influencing the sensory characteristics of the samples.

Principal component analysis (PCA) was used to reduce the dimensionality of the original data and to explore the relationships among the variables. Partial least squares discriminant analysis (PLSDA) was chosen as a supervised method to discriminate between the origin of the samples, based on official and primary attributes.

A study of the frequency of use of the secondary descriptors was carried out using Pearson's chi-squared test, as it is a binary statistic. Moreover, the value in the data matrix is 1 when at least 33% of the tasters indicate that the same attribute is present, while the value is 0 if less than 33% indicate that an attribute is present. This non-parametric test is used to examine the differences between categorical variables in the same population. It can also be used to validate or provide additional context for observed frequencies. In this way, it can be used to determine whether a difference between the observed and the expected data is due to chance, or if it is due to a relationship between the variables under study.

3. Results

3.1. Official and Primary Attributes

All the samples considered in this study were EVOOs, according to the physicochemical and organoleptic parameters.

To evaluate the differences in the sensory profile of the different growing areas, the averages of each attribute for each PDO were statistically analyzed using ANOVA. The results showed significant differences between the three official attributes ('fruity', 'bitter', and 'pungent'), as well as between the four primary attributes ('green', 'astringent', 'almond', and 'walnut') and for the 'complexity' calculation (Table 2) for some of the PDOs. In fact, it can be clearly observed that TA showed the greatest aromatic richness, with significantly higher intensity values for all of the descriptors, except for 'complexity', with similar values being shared with two other PDOs, and 'almond', where it is in second place. It is worth highlighting the high value of the descriptor 'walnut', which is considered to be a particular feature of 'Empeltre', the native variety in this PDO. Regarding BEM olive oils, they provided lower intensity values than TA, but even so, they presented an interesting aromatic profile, marked by their fruity notes and balanced with high values for astringency, bitterness, and spiciness. Regarding the olive oils coming from E, LG, and P areas, they were all very similar to each other, so there were no attributes that allowed them to be clearly distinguished. Finally, C was found to be the area that provided the mildest oils, with the only particularity being that it presented the highest intensity for the primary descriptor 'almond', which has been previously reported [28].

Table 2. Average sensory profile of EVOOs produced in the five Catalan PDOs during the 2012–2020 period. E: Empordà; LG: Les Garrigues; S: Siurana (P: Priorat; C: Camp of Tarragona); TA: Terra Alta; BEM: Baix Ebre–Montsià.

		Explored PDOs					
				S			
Sensory Attribute		**E**	**LG**	**P**	**C**	**TA**	**BEM**
Fruity [1]	**	4.8 ^{c}	4.7 ^{d}	4.9 ^{bc}	4.5 ^{e}	5.5 ^{a}	5.0 ^{b}
Bitter [1]	**	3.8 ^{c}	3.7 ^{c}	3.8 ^{c}	3.5 ^{d}	4.7 ^{a}	4.1 ^{b}
Pungent [1]	*	4.4 ^{c}	4.4 ^{c}	4.5 ^{bc}	4.2 ^{d}	5.0 ^{a}	4.6 ^{b}
Green [1]	*	2.9 ^{b}	2.8 ^{c}	2.9 ^{bc}	2.6 ^{d}	3.5 ^{a}	3.0 ^{b}
Astringent [1]	**	2.0 ^{b}	1.9 ^{c}	2.0 ^{bc}	1.5 ^{d}	2.8 ^{a}	2.1 ^{b}
Sweet [1]	NS	4.3	4.4	4.4	4.4	4.0	4.2
Almond [1]	**	1.0 ^{e}	1.5 ^{c}	1.1 ^{e}	2.3 ^{a}	1.7 ^{b}	1.3 ^{d}
Walnut [1]	**	0.5 ^{c}	0.4 ^{c}	0.5 ^{c}	0.5 ^{c}	1.3 ^{a}	0.8 ^{b}
Apple [1]	NS	0.1	0.1	0.1	0.2	0.0	0.1
Other ripe fruits [1]	NS	0.4	0.3	0.3	0.5	0.2	0.3
Complexity [2]	*	3.2 ^{b}	3.5 ^{ab}	3.6 ^{ab}	2.9 ^{c}	3.8 ^{a}	3.2 ^{b}
Global score [2]	NS	6.9	6.9	6.9	6.7	7.1	6.9
Secondary attributes [3]	NS	2.5	2.4	2.5	2.2	2.8	2.5

[1] Average values within a 10 cm scale of intensity; [2] values calculated as explained in the text; [3] average values for the most intense 'secondary attributes' of each sample. NS: no significant differences, *: $p < 0.05$, and **: $p < 0.001$, according to Fisher's test that uses ANOVA mean squares. In terms of the rows, mean values followed by the same letter are not significantly different according to Duncan's multiple range test ($p < 0.05$).

On the other hand, it was especially striking that the 'secondary attributes' did not show significant differences between the studied PDOs. This finding can be explained by the lack of specificity in terms of these descriptors, which allowed each taster to name these sensory perceptions in their own way, making it difficult to match the same descriptors for 33% of the judges (the value according to which an attribute is considered). Similar results were previously reported by Romero [25], who studied olive oils from LG, P, and C, during the period 1994–2008. Therefore, although the descriptor could be used in terms of intensity, its value is more qualitative than quantitative. It presented an opportunity to obtain a set of undertones perceived by the tasters that provided valuable qualitative information. Thus, when exploring the 'secondary attributes' descriptor, taking into account the different aromas clustered into it, slight differences could be detected among the PDOs.

To visualize the similarities and differences between the samples in a concise manner, principal component analysis (PCA) was applied and the centroids of each growing area

(coordinates in the PCA space of each sample) were plotted. Figure 2a shows the score plot for component 1 *vs* 2, for the six production areas. It can be seen that the three areas where the 'Arbequina' variety predominates (LG, P, and C), their centroid is on the left side or in the center of the plot, whereas those of the other production areas, except E, are located on the right. To obtain a more detailed interpretation of how the samples relate to the variables, in addition to the scores, the loadings were also analyzed. In this way, the contribution of the different evaluated attributes on the different growing areas could be studied. As shown in Figure S1, PC1 is positively correlated with attributes associated with polyphenols (such as 'bitter', 'pungent', and 'astringent') and green aromatic notes [4,29]. Conversely, PC1 has a negative correlation with sweetness (described as the absence of bitterness) and aromatic descriptors related to ripe fruit perceptions. Regarding PC2, it is mainly negatively correlated with mouthfeel attributes, but positively correlated with attributes linked to fruit descriptors and sweetness perception. Finally, combining the analysis of the scores and loadings, a certain correlation can be observed between the sensory profile of each area and the main olive cultivar. Thus, these results corroborate that 'Empeltre' (the main cultivar in TA), 'Morrut' (the main cultivar in BEM), and 'Argudell' (the main cultivar in E) are richer in polyphenols than 'Arbequina' (LG, P, and C), which is a little bit sweeter and less fruity than the others [3]. Nevertheless, while it is possible to observe the abovementioned trends, it is important to note that the distances between the centroids in the score plot are not large enough to avoid the overlapping of individual samples, especially when they come from confluent areas. This means that classification models based only on the main sensory descriptors (official and primary attributes) will have limited utility.

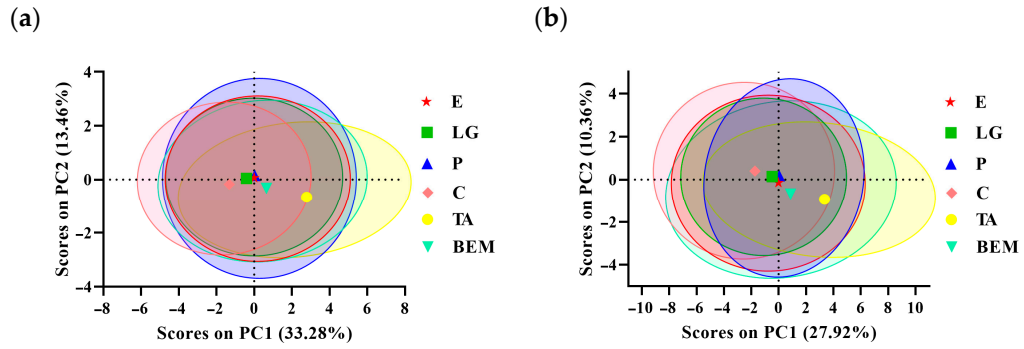

Figure 2. Score plot of the PCA, showing the centroids and ellipses that represent the distribution in terms of the sample and the variability within the regions, according to the sensory attributes of the EVOOs evaluated: official and primary attributes (**a**), official and primary attributes together with the secondary attributes (**b**). Mean values for the six studied production areas in Catalonia, during the 2012–2020 period. E: Empordà; LG: Les Garrigues; P: Priorat; C: Camp of Tarragona; TA: Terra Alta; BEM: Baix Ebre–Montsià.

To try to improve these results, the individual secondary attributes were also added to the data matrix and the new PCA score plot is plotted (Figure 2b). A clearer differentiation can be observed, as the centroids of the LG, P, and C zones are on the positive axis of PC2, while those of the other three zones are on the negative axis. As far as the loadings plot is concerned (Figure S2), the results show a similar correlation between the PCs and the sensory perceptions, than those obtained when solely dealing with the official and primary attributes, but, in this case, there are a higher number of descriptors related to each perception. In any case, although including all the secondary attributes can improve the classification ability, the different way in which primary and secondary attributes are evaluated (using a 0–10 scale and considering a percentage above 33% of the tasters, respectively) poses a challenge to the statistical analysis, due to the disparity in the measurement methods. Moreover, it should be taken into account that increasing the number of variables can also increase the variability of the response. These arguments could explain why the

PCs in Figure 2b present a lower percentage of explained variability than those in Figure 2a. From these results, it was concluded that a deeper analysis of the secondary attributes was necessary.

3.2. Secondary Attributes

Since the secondary attributes were freely chosen, the frequency of use of each secondary descriptor for each studied area was examined by using a box plot (Figure 3). Within each zone, the secondary descriptors are sorted according to their median of use (percentile 50%). The box limits range from the 25th (bottom) to the 75th (top) percentile. As can be seen, the tendency in the use of secondary descriptors for each area is different. In fact, the only coincidence is that 'green fruity' was the most used secondary descriptor in all the areas, being used by 100% of the tasters in TA and BEM for 75% of the samples. The rest of descriptors were different or were ordered differently in each zone. Thus, whereas in E 'ripe fruity' and 'green grass' were used by 60% of the tasters for 75% of the samples, in LG, P, C, and BEM, the prevalence of the 'ripe fruity' descriptor was similar, but 'green leaf' was perceived instead of 'green grass'. Concerning TA, 60% of the tasters identified 'green leaf' and 'artichoke', but 'ripe fruity' was declared for 75% of the samples by only 50% of the tasters, together with 'tomato plant', while in E, P, and BEM 'artichoke' was a descriptor used by 50% of the tasters for 75% of the samples. Regarding attributes used by up to 40% of the tasters when describing 75% of the samples, 'banana', 'fennel', 'green almond', and 'tomato' descriptors were the ones used for the samples from E and P; 'artichoke', 'banana', and 'tomato' were the attributes found in the samples from LG and C, together with 'green fruity' in the samples from LG, and 'fennel' in the samples from C. Other descriptors with less weight in terms of the differentiation between the different areas were those used by around 40% of the tasters. These were 'green grass', 'green almond', and 'ripe fruity' in the TA samples and 'green almond', 'tomato plant', and 'fennel' in the BEM samples. Finally, secondary descriptors such as 'verdure', 'anise', 'flower', 'mint', and 'fig leaf' were anecdotic, as they were used by less than 33% of the tasters, suggesting that they might not be representative characteristics.

To statistically analyze the frequency of use of each secondary descriptor in the EVOOs for each production area, the descriptors used by at least 33% of the tasters were considered (Table 3). Pearson's chi-square test showed significant differences among the different areas in regard to 13 out of the 17 descriptors, with the descriptors 'fennel', 'green to ripe fruity', 'verdure', and 'anise' being the ones that did not contribute to the differentiation between the zones. Regarding the descriptors displaying statistically significant differences, 'green grass' was the most frequently used term across all the studied areas, being outstanding in terms of the C zone. However, the second most frequent descriptor 'green fruity' was used for less than 50% of the samples in this zone. The third most used attribute 'artichoke' was frequently used in terms of the samples from BEM, E, LG, and P, and very frequently used in terms of the samples from TA and less used in terms of the samples from C. The prevalence of 'green almond' ranged from 27 to 44% across the different areas, yet its occurrence in regard to S was only identified in 17% of the samples. Moving to the descriptor 'tomato plant', it was only found to be frequent in terms of the samples from TA, appearing in regard to 50% of the samples, while in the samples from BEM, E, LG, and P it was described in less than 35% of the samples and is very unusual to be used in regard to the samples from C. On the contrary, in the C zone it is very usual (more than 50%) to find the smell of tomato fruit, an uncommon attribute in TA. Concerning the 'banana' attribute, the Official Tasting Panel of Virgin Olive Oils of Catalonia uses it to describe EVOOs exhibiting a ripe banana aroma, while the term 'green banana' is reserved for this other aroma. As for its frequency of use, it was seldom used in regard to TA and BEM samples but appeared in 29–41% of samples from the other areas. In reference to the descriptors 'green leaf' and 'ripe fruity', they were unusual in terms of the BEM, E, LG, and P samples (around 15–22% of the samples) but, while the first descriptor was very common in samples from TA (52%) and very rare in samples from S (less than 5%), the second descriptor was quite common in

samples from S (44%) and very rare in samples from TA (4%). Finally, the attributes 'green to ripe fruity' and 'verdure' were frequently used by tasters, but did not show significant differences among the olive-growing areas.

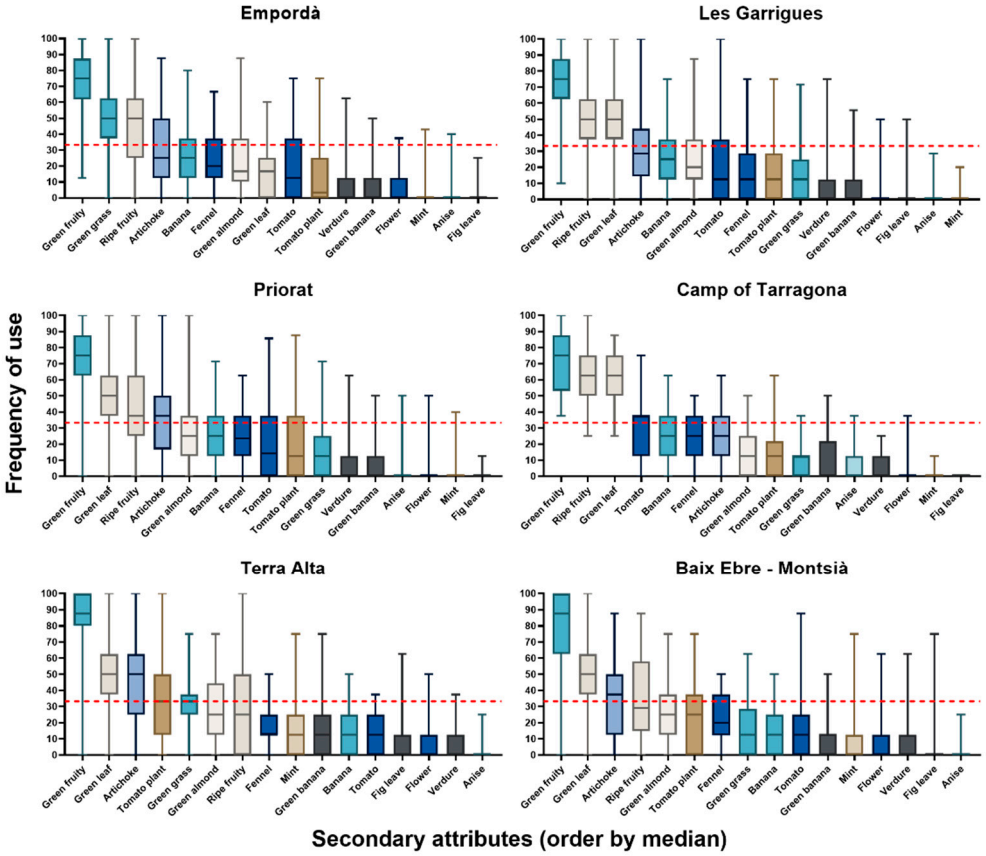

Figure 3. Box plots illustrating the percentage of panel tasters declaring certain secondary sensory attributes in olive oil samples, across the studied areas, from 2012 to 2020. Each box top and bottom represent the 75th and 25th percentiles, while outliers are identified by vertical lines, indicating values deviating more than three standard deviations below the average. E: Empordà; LG: Les Garrigues; P: Priorat; C: Camp of Tarragona; TA: Terra Alta; BEM: Baix Ebre–Montsià. The red line in the graphs indicates that 33% of assessors perceived the sensory notes.

Table 3. Frequency of use (expressed in %) of secondary attributes found in EVOOs produced in the five Catalan PDOs, during the 2012–2020 period. E: Empordà; LG: Les Garrigues; S: Siurana (P: Priorat; C: Camp of Tarragona); TA: Terra Alta; BEM: Baix Ebre–Montsià. The statistical significance of the differences (*p* values) calculated by Pearson's chi-square test is also indicated (NS = not significant, * = $p < 0.05$, ** = $p < 0.01$, and *** = $p < 0.001$).

	Studied Zones (Number of Oil Samples)						
	E (160)	**LG (572)**	**S (401)**		**TA (70)**	**BEM (127)**	
			P (355)	**C (46)**			
Secondary Descriptors	**% of Use**						***p***
Green grass	83	83	78	96	86	85	*
Green fruity	69	67	72	46	91	71	***
Artichoke	46	49	55	33	73	54	***
Green almond	31	27	33	17	44	40	**
Tomato plant	23	25	30	15	50	33	***
Fennel	28	28	27	35	24	33	NS

Table 3. *Cont.*

	Studied Zones (Number of Oil Samples)						
	E (160)	LG (572)	S (401)		TA (70)	BEM (127)	
			P (355)	C (46)			
Secondary Descriptors	% of Use						*p*
Tomato	27	33	30	52	7	19	***
Banana	29	34	37	41	10	10	***
Green leaf	18	19	13	4	52	22	***
Ripe fruity	22	21	16	44	4	19	***
Green to ripe fruity	9	13	12	11	4	10	NS
Mint	4	0	2	0	17	10	***
Green banana	3	3	5	4	13	5	**
Verdure	4	3	3	0	4	7	NS
Flower	3	2	2	2	6	6	*
Fig leaf	0	0	0	0	4	4	***
Anise	1	0	1	2	0	0	NS

4. Discussion

According to the results, the 'green grass' attribute stands out with the highest frequency of use across all the samples from the PDOs, except for TA, ranging from 78% to 96% among the different studied zones. Following closely is the 'green fruity' descriptor, as the second most utilized attribute in regard to the samples from all the PDOs except TA, where it takes the first position. In this case, the range of values for the frequency of use is broader, spanning from 46% to 91%. Despite significant differences between both descriptors across the samples from the various areas, it is particularly noteworthy that the two subzones P and C, which make up the Siurana PDO, behave so differently. In fact, while the Camp of Tarragona area presents the highest value in terms of the frequency of use for the 'green grass' attribute and the lowest for the 'green fruity' one, the Priorat subzone demonstrates the opposite pattern, with the lowest frequency for the first attribute and the highest (except TA) for the second. This different behavior highlights the importance of addressing these subzones independently and it is reinforced by the findings related to the other descriptors (Table 3). The obtained results corroborate the fact that different varieties exhibit different aromatic profiles [30] and that the same variety grown in different areas can yield extra virgin olive oils with different characteristics [31,32]. However, as far as we know, it is the first time such differences have been noted when dealing with secondary descriptors.

Another interesting attribute is 'artichoke', a notable aroma commonly found in premium EVOOs from Catalonia. Its prevalence varies, ranging from 46 to 55% in olive oils from E, LG, P, and BEM, but reaching as high as 73% in the case of TA olive oils, underscoring its distinctive influence on the aromatic profile of this production zone. On the other hand, regarding the 'green almond' attribute, it is important to note that it is described more as a retro-nasal and mouth sensation, rather than solely an aroma. Moreover, this perception is linked to the unripe stage of almonds, which often explains the fresh and pleasant sensation reported by the panelists when evaluating the olive oil featuring this aromatic note.

It is a matter of fact that the environment influences the stress experienced by the olive tree, thereby modulating the amount of polyphenols in oils and, consequently, the non-volatile part of their profile (bitterness, pungency, and astringency). Similarly, it is accepted that the environment may influence the gene expression of enzymes associated with the lipoxygenase (LOX) pathway, which determines the formation of volatile compounds related to green notes, such as 'green fruity', 'green leaf', 'green banana', 'green almond', 'green apple', 'green tomato', 'tomato plant', 'artichoke', and 'verdure' [33].

Regarding the bidding specifications of the different Catalan PDOs, they already consider the use of some secondary descriptors. Thus, the tender specifications of the BEM

PDO describe the olive oil produced in this zone as rich in green secondary aromas [16], which matches our observations, showing a mean profile with a robust character in the mouth. Among the green notes, 'green grass' and 'artichoke' stand out as typical descriptors in terms of the 'Morrut' variety, while 'green almond' and 'fennel' are characteristic of 'Farga' and 'Sevillenca', respectively, which are the three typical varieties in this production area. Regarding the TA PDO, its bidding specifications indicate that its olive oils may have 'almond' or/and 'walnut' aromas, a common characteristic of the native variety 'Empeltre' [15]. This description aligns with the findings presented in Table 2. It should be noted that TA shares some geographical influences from the Ebro River with BEM, resulting in TA extra virgin olive oils also notably being herbaceous. Furthermore, in this production area, there has been a recent trend in advancing the harvest to mitigate the risk of frost damage. This trend could also explain the frequent use of descriptors such as 'green leaf', 'artichoke', and 'tomato plant'.

Concerning E, the typical description includes green fruity notes [12], which has a prevalence of 69%, according to our results (Figure 3), along with a green secondary aroma [20], mainly associated with 'green grass', as depicted in Table 3.

For LG and S, any secondary descriptor is allowed. However, both bidding specifications [13,14] describe two different profiles based on the harvest season, namely 'green' and 'ripe fruity', which indeed are the most used secondary attributes by the tasters to characterize olive oils from these areas (Figure 3). If we focus on each area more specifically, it is important to note that the PDO in S consists of P and C subzones. P is an area located between LG and C, where the 'Arbequina' variety predominates. The aromatic profile of the olive oil from this area is more 'fruity', 'greener', 'bitter', and 'pungent' than the average profile of olive oils from zone C in the S PDO. The 'green fruity' descriptor shows significant differences (Table 3), because in the P zone harvesting begins earlier to avoid the high risk of winter frost. In contrast, the olive oil profile of the C subzone presents 'banana' and 'tomato' notes much more frequently than the P subzone, and even more so than in LG, where harvesting is also conducted earlier to avoid frost effects. Furthermore, in C, both 'green fruity' and 'ripe fruity' descriptors have a similar frequency of use, being the only production area where this occurs. This could be attributed to the faster ripening of olives in area C compared to those in the interior regions, resulting in the simultaneous processing of both green and ripe olives. Another notable observation in terms of this zone is the low frequency of 'tomato plant' and 'artichoke' descriptors, as well as the very low frequency of the 'green leaf' descriptor. On the other hand, LG has a mean profile similar to P, due to the proximity between both zones, but with a slightly greater intensity in regard to 'almond' (Table 2). The decrease in the frequency of 'green fruity' notes and the increase in 'ripe fruity' notes compared to P might be attributed to irrigation near the harvest date in the new high-density orchards. This results in an increase in difficult pastes during the extraction process and, consequently, many of these EVOOs have a lower fruity intensity than intended. However, the presence of the 'green leaf' attribute is higher in LG than in P, S, and even E. Finally, when considering the official and primary descriptors, 'bitter' exhibits the lowest values for samples from C, possibly due to lower environmental stress. However, the 'sweet' attribute shows similar values for LG, P, and S, indicating similarities among these areas.

It is evident that the tasting panel usually choses the same secondary attributes when evaluating EVOOs from the same Catalan PDO due to the interaction between the production areas and the olive cultivars. This implies that there is a combination of secondary descriptors specific to each zone and that some attributes are preferentially used before others, as can be seen in Table S1.

5. Conclusions

The varying prevalence of secondary attributes across the different Catalan PDOs demonstrates its potential as a discriminatory tool and it aligns with the current bidding specifications, despite most of these specifications being drafted several years before the

systematic application of descriptive sensory analysis in the Catalan olive oil sector. The limitations in terms of their discriminant capacity are mainly due to the fact that these descriptors are freely proposed by each taster for each sample, rather than being selected from a closed, standardized list that is periodically used for training purposes like that of the official and the primary descriptors. Therefore, systematizing the secondary attributes most frequently associated with each Catalan PDO would enhance EVOO classification. This approach would involve evaluating the selected secondary attributes, alongside the official and primary descriptors. When analyzing EVOOs from a specific Catalan PDO, the combination of the most relevant secondary attributes should achieve a certain score to ensure that these samples unequivocally reflect the aroma derived from the particular climatic conditions, geographical environment, and cultivars in that PDO. This would help prevent fraud related to PDO affiliation, resulting in a more accurate evaluation and classification of EVOOs produced in Catalonia, thereby increasing their value.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy14102218/s1, Figure S1: Loadings of the canonical variables calculated for the official and primary attributes of EVOOs from the five studied Catalan PDOs areas during the 2012–2020 period; Figure S2: Loadings of the canonical variables calculated for the official, primary and the secondary attributes of EVOOs from the five studied Catalan PDOs areas during the 2012–2020 period; Table S1: Attributes of EVOOs from the five Catalan PDOs production areas during the 2012–2020 period ordered from the highest to the lowest frequency of use for each zone. E: 'Empordà'; LG: 'Les Garrigues'; S: 'Siurana' (P: 'Priorat'; C: 'Camp of Tarragona'); TA: 'Terra Alta'; BEM: 'Baix Ebre-Montsià'. Same color is used for same descriptor.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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