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Structural Equation Modelling (SEM) applied to sensory profile of Vinho Verde monovarietal wines

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Abstract

Vinho Verde is the biggest DOC of Portugal, and it produces wines distinguished by their high acidity and flavor. In this Portuguese wine-region, three grape varieties, Alvarinho, Loureiro, and Arinto, are used to produce monovarietal wines of great quality.

Sensory characterization of wines has the aim of detecting unique qualities in wines, and the most common measurement for the sensory aspects of wines sensory profile is descriptive sensory analysis, typically performed by trained sensory panels. To a list of attributes that can characterize a wine, we call a "sensory lexicon" that can be used by marketers allowing the articulation of flavor perceptions to consumers.

So, the aim of this work was to recruit and train a sensory panel able to describe the sensory aspects associated with the monovarietal wines from Loureiro, Arinto and Alvarinho grape-varieties. Furthermore, a second order factor analysis statistical model was developed for each grape-variety wine, based on the data-set of sensory attributes, allowing a new perspective in the sensory characterization of these wines.

We discover that there are some similarities between the sensory lexicons that can be used to better describe the wines. However, there are descriptors that specify each monovarietal wine. Loureiro wines present "Loureiro and mineral aromas"; Alvarinho wines are described by having "citrus" aroma and freshness in the mouth and Arinto wines possess a distinctive fruity aroma (peach and pineapple) with an alcoholic, acid and fresh flavor. Additionally, it was also shown that Structural Equation Modelling (SEM) is a **worthy** statistical tool to be used in sensory analysis data treatment.

Keywords:

Sensory profile, flavor lexicon, Alvarinho, Arinto, Loureiro, **second-order** factor analysis.

1. Introduction

A wine´s typicity depends on his characteristics and if they can be identified and make it recognizable as belonging to a certain grape variety or region (Maitre et al., 2010). Moreover, "typicity" is a term in wine tasting used to describe the degree to which a wine reflects its varietal origins, and thus the wine demonstrates the signature characteristics of the grape from which it was produced. Wines with 'typicity' - that are typical of a varietal/region are said to exhibit traits or characteristics distinctive to its kind. For instances, vineyard geology—bedrock and overlying soils—is widely supposed to help explain the typicity of wine from a particular area (Maltman, 2008). Vinho Verde Demarcated Region of Portugal, was originally defined on September 18, 1908. It extends across the northwest of Portugal. The Minho River is its northern border, forming part of the border with Spain, its southern border is formed by the Douro River and the Freita, Arada and Montemuro mountains, to the east it's bordered by the mountains of Peneda, Gerês, Cabreira and Marão, and the western border is the Atlantic Ocean. In terms of geographical area, it is the largest Portuguese Demarcated Region, and one of the largest in Europe (CVRVV, 2017). Topographically, the region is "a vast amphitheater which, starting at the coast, gradually climbs in elevation towards the interior" exposing the entire area to the influence of the Atlantic Ocean, a phenomenon reinforced by the orientation of the valleys of the main rivers, which run east to west and facilitate penetration of the sea winds. This Atlantic influence, mostly granitic soils, mild climate and high rainfall, are reflected in the freshness and lightness of the wines of this region. Variations in the types of soils and microclimates justify the division of the region into nine subregions (Figure 1), with different grape varieties recommended for the production of still wines, spirits and sparkling wines (CVRVV, 2017). The still wines are distinguished by its high acidity and flavor that depends on the grape varieties used. Most white Vinho Verde wine can be relied upon to be light, crisp and aromatic, often with a light prickle of fizz, sometimes with a touch of sweetness (CVRVV, 2017).

Alvarinho is a grape-variety cultivated particularly in the subregion of Monção and Melgaço (Figure 1). Arinto grapes grown throughout the region but, it reaches its highest level of quality in inland areas of the region and Loureiro grape-variety grows in almost every region but is best suited to coastal areas (CVRVV, 2017).

Sensory characterization of wines has amongst its aims detection of distinguishable qualities in a wine (Green et al., 2011). Conventional sensory profiling has been used within the framework of the typicality concept (Cadot et al., 2010; Perrin et al., 2008; Maitre et al., 2010). The primary measurement for the sensory aspects of wines flavor is descriptive sensory analysis, usually performed by trained sensory panels (Chambers et al., 2004) using methods that classically examine the sensory perceived wine attributes and measure their intensities (Hootman, 1992). Of particular importance is the "designation" of attributes. This is important in order for multiple researchers, in various laboratories, to have a basis for understanding the product. To develop attributes it is useful to use definitions or references intended for individually describe them. To a list of attributes that can characterize a wine we call a "sensory lexicon". Lexicons aid in communication between researchers, product developers, manufacturers and can also be used in **the quality** assessment. Moreover, they aid marketers by allowing the articulation of flavor perceptions to consumers. Lexicons typically contain terminology for multiple sensory perceptions: flavor, aroma, aroma-by-mouth, taste, mouthfeel, and trigeminal sensations. Some have been published related to wine (Noble et al., 1984 and 1987; Corsi et al., 2013; Monteiro et al., 2014) or distilled beverages, like rum (Ickes et al., 2017), whisky (Lee et al., 2001), cognac (Lurton et al., 2012), brandy (Jolly & Hattingh, 2001), and even beer (Parker, 2012). The wine flavor wheel, Created by Ann C. Noble at UC Davis in the 1980s (perhaps last revised in 1990), helped codify what was then an emergent discipline: "objective" description of wine; is one of the most well-known lexicons and one of the first to be constructed.

The development of a lexicon requires the use of a trained sensory panel (Lawless & Civille, 2013). Aiming to develop a comprehensive lexicon of a certain wine-type or grape-variety, like with other food products (Drake et al., 2001), wine-samples from different winemakers and produced in various geographical regions must be evaluated. Once the wines have been selected, panelists will generate terms (attributes/descriptors) to describe their perceptions. The determination of appropriate chemical references and the development of specific definitions for each attribute is also made (Monteiro et al., 2014). Once the terms and references have been determined, the lexicon will be organized into a comprehensive list (Monteiro et al., 2014, Vilela et al., 2015). **Afterward,** panelists start by scaling the attributes according to the selected references and a structural scale. Each sample is then evaluated by the panelists with each attribute being rated in comparison to its corresponding reference (Monteiro et al., 2014). The compiled data allow researchers to identify how products within the category differ from each other (Lawless & Heymann, 2013).

After collecting all the data, a statistical treatment is needed, so that the data obtained can be correctly analyzed and interpreted. Correspondence Analysis (CA) (Mc Ewan & Schich, 1991, 1992), Multidimensional Scaling (MDS) (Popper & Heymann, 1996), DISTATIS (Abdi et al., 2007), exploratory data analysis techniques—Principal Component Analysis (PCA) and Canonical Variate Analysis (CVA) (Hopfer et al., 2014) and Categorical Principal Component Analysis (CATPCA) (Monteiro et al., 2014, Vilela et al., 2015) are the common methods used for data reduction and analysis. In this study, we present a structural equations modeling methodology, SEM, for identifying Vinho **Verde** wine sensory characteristics. Despite the increasing researcher work in the field of sensorial analysis, to the best of our knowledge, there are no studies were the researcher adopted this methodology to describe the sensory aspects associated with wine or food.

Structural equation modeling had its origin in the beginning of the 20th century from seminal works of the geneticist Sewall Wright which solved simultaneous equations with the aim of **explaining** genetic influences through generations (Wright, 1921, 1934) and Charles Spearman (Spearman, 1904). Frameworks of Jorëskog (1970), Keesling (1972), and Wiley (1973) allowed the generalization of this methodology to social and behavioral sciences (Ho, 1999; Cordova at al., 2000). In the past decade, SEM received a great deal of attention from researchers in different areas of knowledge like ecology and forestry (Fan et al., 2016; Lam & Maguire, 2012), social sciences like psychology (MacCallum & Austin, 2000) and network meta-analysis (Tu & Wu, 2017); it ranges from the psychometric validation of instruments to the analysis of invariance of models between groups. SEM is a confirmatory statistical method, based **on** a theoretical model established *a priori* by the researcher, and the data serve to confirm or not the theoretical model. More specifically, various theoretical models can be tested in SEM that hypothesize how sets of variables define constructs and how these constructs are related to each other. In SEM the model is formulated as a system of equations that relates several random variables with assumptions about the variances and covariances of random variables and takes into account potential errors of measurements in all observed variables. The variables involved could be observed (manifest) or latent, i.e., variable for which there are no available observations, but manifest themselves in other observed variables. **They can also be defined as independent (*exogenous*) or dependent (*endogenous*) variables, whether they are observed or latent.**

Using SEM, researchers can specify regression models, path analysis models, factor analysis models and latent change models (Marôco, 2014b). The main advantages of SEM are: i) take measurement error into account by explicitly including measurement error variables in all observed variables, ii) incorporation of unobserved variables with multiple indicators, iii) to model

ant test complex patterns of relationships and iv) test local and global assessment and specific assumptions about parameters for their compatibility with the data.

The overall objective of this work was the sensory characterization of the monovarietal wines from Loureiro, Arinto and Alvarinho grape-varieties, all produced in sub-regions of Portugal Vinho Verde Demarcated Region. For that purpose, a sensory panel was recruited and trained in order to develop a suitable flavor lexicons.

In this study, a confirmatory factor analysis (CFA) was used to test hypotheses concerning the **relationship** between observed variables and their underlying latent constructs. CFA implies the formal specification of the measurement instrument in terms of a factor model, the statistical fitting of the factor model to the observed data (variances and covariances, or correlations), the assessment of fit, and the interpretation of whether the model is consistent with the data (Bollen, 1989).

So, the overall objective of this work was to recruit and train a sensory panel and then, describe the sensory aspects associated with the monovarietal wines from Loureiro, Arinto and Alvarinho grape-varieties, all produced in sub-regions of Portugal Vinho **Verde** Demarcated Region, allowing the development of suitable flavor lexicons. Moreover, a second order factor analysis model was developed based on the data-set of sensory attributes, allowing a new perspective in the sensory characterization of monovarietal Vinho **Verde** wines.

2. Materials and methods

2.1. *Wine samples*

For terms generation, nine monovarietal wines, selected from the 17 wines studied, were used. Three wines from *Vitis vinifera* Alvarinho cultivar (AL1 - AL3), three from Arinto (AR1 – AR3) and another set of three from Loureiro cultivar (L1 - L3). These wines were tasted and discussed by the panelists. Afterwards, for the establishment of the monovarietal wines sensory profile, the sampling set included 17 commercial monovarietal white wines (six Alvarinho wines coded QLNA, QLXA, QRA, QAA, QPVA, and QCA; four Arinto wines coded QL; QA1; QR and QA2; seven from Loureiro grape-wine variety, coded QL, QLI, QA, QPLL, QCL, QDM and QAM). The wines came from several vintages (2013-2015) and several Vinho **Verde** sub-regions (Basto, Cávado, Lima, Monção-Melgaço, and Sousa **– Figure 1**). The wines were stored in a climate-controlled dark cellar maintained at 11ºC (±1ºC). **Generally,**

white wines are served cold, however, once this was not a consumer study, the day before the sensory sessions, the wine bottles were stored at room temperature (20ºC ± 2ºC). In this way, all aromas, flavors and tastes could be easily perceived by the tasters. In the day of the session, the panel leader checked that the wines were free of cork taint and other detectable defects.

2.2. *Sensory Analysis Facility and general sensory procedure*

Evaluations took place in individual tasting booths under white lights at Aveleda S.A. Sensory Evaluation Facility. All evaluations were conducted from 10:00 to 12:00 p.m. in individual booth/panelist (ISO 8589, 2007), using the recommended glassware according to (ISO 3591, 1977). Sessions were carried out under controlled conditions of temperature (20ºC ± 2ºC) and relative humidity (60 ± 20%). A wine volume of 50 mL was used, in all the tasting sessions, in order to be possible for the tasters to repeat the analysis. The samples were presented in random order (ISO 6658, 2017).

2.2.1. Panelists and training

It was also the goal of our work to train a sensory panel at Aveleda S.A. that could continue working in sensory tests since this company did not had a trained sensory panel. Moreover, the use of "wine experts" is expensive, and some training must always be performed.

The panelist's selection-training comprised three stages: recruitment, selection, and training. After recruitment, by means of sending an email to all the employees of Aveleda S.A., the initial selection was carried out with a questionnaire, in order to determine personal aspects, such as health, smoker/non-smoker, availability, linking/disliking wine and other factors of a general nature. Explanations were given based on the theory of wines sensory evaluation.

The panelist´s training occurred during 16 sessions of 2 h each according to ISO 13300 (2006). There were two sessions per week, from 10:00 to 12:00 p.m. An interval of 15 min was imposed in the middle of the session to limit panelist fatigue. However, during the session, the panelists had the opportunity to take a break when they considered it necessary.

For taste perception training a sample of each representative basic taste was presented to each candidate, and they were left to familiarize themselves with the basic tastes - sweet, sour and bitter, with solutions of sucrose (32 g/L), citric acid (1.0 g/L) and quinine (5.0 mg/L). **Afterward**, with the aim of the study being to determine their detection threshold, they were presented with the Vinho **Verde** associated tastes – sweet, sour and bitter at lower and higher levels than the detection threshold associated with Vinho **Verde.** For the sweet taste six sucrose solutions were prepared with 0; 5; 10; 15, and 20 g/L of sucrose; for the sour taste six citric acid solutions with 0; 0.05; 0.15; 0.40; 0.70 and 1.0 g/L of citric acid, respectively, and for the bitter taste six solutions of tannin (®Volutan) with 0; 0.5; 1.0; 2.0; 5.0 and 10.0 mL/L. These solutions were prepared **with** mineral water.

The color perception training took place in one session. Candidates were presented with four color samples of Vinho **Verde** and they were then asked to classify the samples in terms of color intensity and hue. Figure 1 is an example of Vinho **Verde** wine colors.

The olfactory perception training occurred over five sessions. For a better understanding of the Vinho Verde wine aroma, the white Wine Aroma Wheel retrieved from http://merchantsfinewine.com/faq-items/wine-aroma-wheels/, was provided to the panelists, Figure 2, and natural products associated with Vinho **Verde** wine aroma were also provided in sensory tasting glasses. Several aromas were used in the initial sessions with the purpose of introducing the panelist to the aromas, as well as to the defects of the wines. Panelists were asked to smell the fragrances and mentally classify the sensory perceptions identified, noting down the associated descriptors.

The sessions that followed were intended for aromas and defects perception training. In the first phase, solutions of linalool, acetaldehyde, ethyl acetate, acetic acid and TCA (2,4,6-trichloroanisole) were distributed to the panelists. They were asked to smell and at the same time, a brief presentation was made on each of these compounds. Subsequently, it was performed a ranking order test with those same aromas and defects. The solutions were prepared with four different concentrations: "C1" concentration below the theoretical olfactory perception threshold; "C2" concentration in the theoretical olfactory perception threshold; "C3" concentration slightly above this threshold and "C4" a higher concentration, usually noticeable by most individuals (Table 1). The glasses with the solutions were randomly distributed and the panelists should smell the glasses from left to right and then place them in the increasing order of intensity, "1" less intense and "4" more intense. They were also asked to identify the aroma or designation of the substance. This test was repeated one more time to ensure the reproducibility of the results.

To evaluate the discriminatory capacity of the tasters, a triangular test was performed. The triangular test is a test of forced choice and aims to detect the presence or absence of sensorial differences between products. Three samples were presented simultaneously, two being equal and only one different. All samples were coded and the tasters would have to identify the different sample. Four triangular tests were performed. For each test three glasses were presented, two white samples (mineral water, at room temperature) and one (the different sample) containing mineral water contaminated with acetic acid, acetaldehyde, ethyl acetate or TCA (Table 1). This test was performed in duplicate for a better reproducibility of the data and the tasters were being informed of the results obtained.

*2.2.2. Identification, selection of descriptors and development of references for Vinho **Verde** wines*

For terms generation, nine monovarietal wines from the grape-varieties Alvarinho, Arinto, and Loureiro were tasted and discussed by the panelists over three sessions, one session for each grape variety. A free choice of attributes to describe Vinho **Verde** wines was used. Each session lasted around 2 h. The White Wine Aroma Wheel (Figure 2), was, once again, provided to facilitate terms generation. From an original long list of attributes, a reduced list was compiled by analyzing the frequency of citations.

For the development of quantitative references and in order to make reference evaluation as close as possible to wine-tasting conditions, identical glasses as used for wine evaluation (ISO 3591, 1977) were used for the aroma reference presentation. After all the references were developed, three training sessions were carried out according to the methodology that would be used to evaluate the wines and described by other authors (Etaio et al., 2008; Monteiro et al., 2014) and according to ISO 13299 (2016).

2.3. *Wine tasting*

In this study, we analyzed seventeen monovarietal Vinho **Verde** commercial wines available in the Portuguese market and produced in the Vinho Verde Demarcated Region. All the wines were evaluated in duplicate in three tasting sessions, one session for Alvarinho wines, the second for Arinto and the third for Loureiro monovarietal wines. As it was mentioned before, the session occurred from 10.00 a.m. to 12:00 noon. The wines were randomly distributed throughout the sessions of each series. References were served in standardized wine-tasting glasses. Wine bottles were opened immediately before tasting, and 50 mL samples of each wine were served. References and wine glasses were covered with Petri dishes and were immediately brought to the tasting booths in the sensory evaluation laboratory.

Attribute intensities were scored on a five-point scale (ranging from 1, lowest intensity, to 5, highest intensity), adapted from Monteiro et al. (2014), by comparison with the intensity of the references. The panelists were instructed to give scores to the attributes in the order they perceived them and they were also instructed to rinse with water between references and between wines, as well as to use unsalted crackers to decrease astringency carry-over. The panelists were told to have a rest and to leave the tasting room if necessary.

2.4. *Data analysis*

For the sensory data analysis, skewness (Sk) and kurtosis (Ku) coefficients were computed for univariate normality analyses purposes, and all values were within ±2 range. Confirmatory factor analysis was used to test how well the theoretical model explains the covariance among items. Specifically, to identify the sensory profile structure of Vinho **Verde** wines we adopted a second order factor analysis to test if there were underlying factors among the sensory attributes (first order) and if those latent factors loaded on the common sensorial profile factor (second order). For the estimation of the parameters we used the maximum likelihood method, as which provided us with the standardized estimates of the coefficients (an estimate higher than 0.5 in absolute value indicates a strong association), standard error, Z Test and *p*-value (if *p*-value<0.05, then that parameter is significantly different from zero). The existence of outliers was evaluated by the square distance of Mahalanobis (D^2) and the normality of the variables was evaluated by the skewness (Sk) and kurtosis (Ku). Comparative Fit Index (CFI), Goodness of Fit Index (GFI), **Root-Mean-Square** Error of Approximation (RMSEA) fit indices and χ2 statistics were used to determine the adequacy of the models. A CFI>0.90, GFI>0.90, and RMSEA<0.05 with 90% CI<0.10 are acceptable indices of fit for the model and χ^2/df<2 is considered to be good (Ho & Bentler, 1998; Byrne, 2001; Marôco, 2014a). All statistical **analyses were** performed using software SPSS 22.0 (IBM SPSS 22.0, Chicago, IL) and AMOS (v. 22, SPSS, An IBM Company, Chicago, IL).

3. Results

3.1. *Panelists selection*

Control of the human aspect of sensory evaluation is one of the more difficult factors of sensory evaluation. This may be accomplished best by carefully selecting the people that will be participating in the test. Important qualities in a sensory panelist include availability, dependability, interest, objectivity, stability, and acute senses of smell and taste. The panelist's selection comprised **of** three stages: recruitment, selection, and training. The recruitment of the tasters was carried out on a group of thirty-six employees of Aveleda S.A., 24 men and 12 women, aged between 23 and 57 years, from different departments of the company: management, accounting, commercial, oenology-quality, oenology-production, logistics, winery, administration, strategic planning, maintenance, information systems, wine tourism, catering and viticulture. Of the total number of participants, 44% had a Bachelor's degree and 30.6% the 12th grade, and the remaining 25.4% **had** a level of education equal to or less than the 9th grade. After recruitment, the initial selection was carried out with a questionnaire.

After the questionnaire analysis, **three-panel** candidates were eliminated due to health restrictions. For reasons of hourly incompatibility and given that some sectors of the company considered that the sessions would occupy too much time of their collaborators. Only 21 candidates attended the first session for selection/training and from this group only in eleven, the success rate in the ranking order tests of basic tastes (sweet and sour) and the **mouth-feel** sensation of astringency was very satisfactory, compared to previous studies (Monteiro, 2012), reaching 70%. So these tasters went on to the next phase. The remainder were eliminated for the following reasons: demonstration of lack of interest in the tests, low rate of attendance or failure to achieve the desired success rate.

The results obtained in the identification and ordering of aromas and defects served for a new selection of the tasters, as well as the triangular test. The tasters performed four triangular tests and the success rate was 100%, thus demonstrating the ability of the entire panel in identifying differences between samples. As a result, no tasters were eliminated in this test, being selected to participate in the development phase of descriptive terminology. So, the final panel of tasters consisted of eleven tasters, nine men and two women, between the ages of 23 and 40 years. The panelist, in the next sessions, were then subjected to taste, color and olfactory perception training.

3.2. *Panelists training*

3.2.1. *Taste perception training*

The results obtained in the perception threshold test of the basic tastes (sweet, sour and astringency sensation) show that for the sweet taste and for **the mouth-feel** sensation of astringency, the panel is almost consensual as to the concentration necessary for reaching the perception threshold (Figure 3 A and C). Thus, 83% of the panelists had the perception of the sweet taste when the sucrose concentration was equal or superior to 5 g/L (Figure 3 A), 48% **had** the perception of the sour taste at the citric acid concentration equal to or greater than 0.05 g/L (Figure 3 B) and 86% perceived the sensation of astringency at a tannin **solution** concentration of 0.5 ml/L (Figure 3 C).

The success rate of the ranking order test of different intensities of sweet, sour and astringent solutions was quite satisfactory with 70% correct answers. The taste with the highest order success rate was the acid (sour) taste with 82% success rate, whereas the astringency sensation obtained a success rate at the order of 64%. The data obtained are in agreement with those of Elortondo et al. (2007).

3.2.2. *Color perception training*

In the visual examination of the first of the four wine samples, 56.2% of the tasters considered that the wine had a straw yellow hue; the second wine sample, 56.2% of the tasters considered the wine to be golden. The third wine, for 69% of the tasters was greenish yellow whereas, for the fourth wine, 81.2% of the tasters recognized the amber hue. It was interesting to notice that the color intensity of the four wines was considered "slightly intense" 81.2% for the first wine and 68.7, 87.5 and 68.7 for the second, third and fourth wines, respectively, Table 2. The results show a lot of consistency since all of them present a percentage of choice (citation) above 56% (Elortondo et al., 2007).

3.2.3. *Olfactory perception training*

In the olfactory perception training, all together, the identification of natural aromas (natural products associated with Vinho **Verde** wine aroma) obtained positive results. With a success rate of 100% of correct answers, the panelists identify the lemon, melon, and fresh herb and banana aromas. With success rates over 65%, aromas of honey, apple, hazelnut, pineapple, almond, wood, linden, laurel, mango, lavender, walnut, and peach can also be highlighted (Table 3).

In the ranking order test of different intensities of aromas and defects, the results were not so satisfactory. Only 6 of the eleven tasters **were** able to order all the series. This may be due to the fact that the concentrations used were very close to each other. However, the tasters have shown to have some ordering ability in which concerns to the acetaldehyde and ethyl acetate compounds (100% of correct answers), probably because their perception threshold is **significantly higher** when compared with the others.

Four triangular tests were carried out in order to identify the different sample for acetaldehyde, ethyl acetate, acetic acid and TCA solutions. The success rate in the first repetition was 95% and in the second repetition of 100%, indicating a clear evolution of the discriminatory capacity of the panel of tasters.

3.3. *Identification, selection of descriptors and development of references for Vinho **Verde** Wines*

For attributes generation, nine monovarietal wines from the grape-varieties Alvarinho, Arinto, and Loureiro were tasted and discussed by the panelists. From an original long list of attributes, a reduced list was compiled by analyzing the frequency of citations. In Tables I, II and III (supplementary material), we present the final descriptors and respective quantitative references for each monovarietal wine. So, for Alvarinho wines we ended with seventeen descriptors, for Arinto wines, **twenty-two** and for Loureiro monovarietal wines nineteen sensory descriptors.

3.4. *Development of a **second-order** factor analysis model for wines sensory attributes*

Seventeen monovarietal Vinho **Verde** commercial wines available in the Portuguese market and produced in the Vinho **Verde** Demarcated Region were sensorially analyzed. Attribute intensities were scored on a five-point scale according to Monteiro et al. (2014), by comparison with the intensity of the references.

We used the covariance matrix and the maximum likelihood method to test the fit to the observed data of the **three-second** order CFA models. It was considered that the proposed **second-order** CFA model was valid when all items presented factorial weights (standardized coefficients of factorial weights) superior **to** 0.3 and the fit indices of the model presented a good fit to the variance-covariance structure evaluated. The adjustment of the model was made from the modification indices (MI>11) and based on theoretical considerations.

We have not considered, for the **three-second** order CFA models, the descriptors related to wine appearance ("clean" and "yellow") because they did not **verify** the normality conditions (skewness and kurtosis between -2 and 2). Once, it was hypothesized that the underlying structure of sensorial descriptors for each one of Vinho

Verde monovarietal wines comprised one common **second-order** factor Sensory Profile and three **first-order** factors Aroma, **Mouth-feel,** and Flavor.

For Loureiro wines, the results of the initial estimation of the hierarchical factorial structure, i.e., a single **second-order** factor and three **first-order** factors, Aroma with seven descriptors, **Mouth-feel** with also seven descriptors and Flavor with three, did not provided good fit with the data (χ^2/df=4.287; CFI=0.642; GFI=0.729; RMSEA=0.145; P[rmsea≤0.05]=0.000). The descriptors "acid" and "bitter" presented loadings inferior **to** 0.3 so they were eliminated from the model. Based on the modification indices (MI>11), the descriptors "tropical fruits aroma", "citrus aroma" and "vegetal aroma" were also deleted since they loaded not only on the designated factor (Aroma). These deletions significantly improved the model (χ^2/df=1.924; CFI=0.922; GFI=0.916; RMSEA=0.078; P[rmsea≤0.05]=0.041), but not enough for it to reach a satisfying level, which was accomplished after deleting the **Mouth-feel** descriptor "sweet" (χ^2/df=1.683; CFI=0.948; GFI=0.931; RMSEA=0.067; P[rmsea≤0.05]=0.175). Therefore, the final second-order hierarchical model has 10 descriptors, distributed as presented in Figure 4-A.

The descriptive statistics (M±SD) and univariate normality **measure** Sk and Ku for the sensory descriptors specified by the final model are presented in Table 4. Mean values of the descriptors ranged between 1.74 - "mineral aroma" and 2.75 - "persistent" on a possible scale range of 1 to 5. Absolute values of the univariate Sk and Ku were within the range of −2 to +2 and were interpreted as normally distributed.

In Table 5 are reported the second order factor loadings and **its** significance. Each of the first factors strongly loaded onto the second order factor, as follows: Aroma (0.993), **Mouth-feel** (0.818), Flavor (0.996) and are highly significant since their respective *p*-value is lower than 0.01. Therefore, the first order three factors could be explained by a single **second-order** factor, Sensory Profile. As can be seen in Table 6, all the factor loading values are above 0.4 and are highly significant since their respective *p*-value is lower than 0.01, indicating that all items are meaningful in measuring the respective component (**first-order** factor). Thus, the first order factor Aroma is characterized by the descriptors "loureiro aroma", "floral aroma" and "mineral aroma", the first order factor **Mouth-feel** is characterized by the descriptors "persistent", "soft sensation", "body" and "balance", and the first order factor Flavor is characterized by the descriptors "vegetal flavor", "citrus flavor" and "tropical fruits flavor".

For Alvarinho wines, the second-order hierarchical model proposed has 15 descriptors in three **first-order** factors: Aroma with 5 descriptors, **Mouth-feel** with 7 and 3 descriptors for Flavor. After eliminating the descriptors whose loadings were less than 0.3 and removing the descriptors "tropical fruits aroma" and "vegetal aroma", whose modification indices (MI>11) suggested their saturation in different factors and, correlating the measurement errors of descriptors "apple aroma" and "apple flavor", it was possible to obtain a good adjustment quality of the overall model (χ^2/df=1.548; CFI=0.948; GFI=0.918; RMSEA=0.071; P[rmsea$\leq$0.05]=0.185).

Mean values of the descriptors (Table 4) ranged between 2.77 – "sweet" and 3.28 – "freshness" on a possible scale range of 1 to 5. Absolute values of the univariate Sk and Ku were within the range of −2 to +2 and were interpreted as normally distributed.

Figure 4-B shows the values of the standardized factor weights and the individual reliability of each of the items in the final **second-order** CFA. As reported in Table 5, the factor loadings (standardized coefficients) of the **second-order** factor, Sensory Profile, on the first order factors Aroma, **Mouth-feel,** and Flavor are 0.52; 0.83 and 0.98, respectively (Table 5), meaning that Sensory Profile loads well on its three **first-order** factors. The *p*-values **show** all components in the Sensory Profile model are highly significant since their respective *p*-value are lower than 0.01. Furthermore, the **squared** multiple correlations, R^2, for the **first-order** factors are generally high (0.27; 0.69 and 0.96, Figure 4-B), which means that the contribution of Sensory Profile on its first order factors is good.

Table 6 shows the unstandardized and standardized maximum likelihood estimates and **its** significance for the first order factors. As can be seen, all the factor loading values are above 0.5 and are highly significant since their respective *p*-value is lower than 0.01, indicating all items are meaningful in measuring the respective component (**first-order** factor). Thus, the first order factor Aroma is characterized by the descriptors "floral aroma", "citrus aroma" and "apple aroma", **Mouth-feel** is characterized by the descriptors "persistent", "freshness", "body" and "balance", and the descriptors that characterized the first order factor Flavor are "vegetal flavor", "apple flavor" and "tropical fruits flavor" (Figure 4-B).

Finally, for Arinto wines, after removing the descriptors whose loadings were less than 0.3, deleting the descriptors whose modification indices were greater than 11 and having correlated the measurement errors of the descriptors "peach aroma" and "pineapple aroma" it was possible to obtain a good adjustment quality model: (χ^2/df=1.580; CFI=0.917; GFI=0.872; RMSEA=0.086; P[rmsea$\leq$0.05]=0,082). Therefore, this second-order hierarchical model, Figure 4-C, is appropriate to describe the relationship between the observed variables and the latent factors and provides **a good** fit with the data.

The descriptive statistics (M±SD) and univariate normality **measure** Sk and Ku for the sensory descriptors specified by the final model are presented in Table 4. Mean values of the descriptors ranged between 1.95 – "peach aroma" and 3.15 – "freshness" on a possible scale range of 1 to 5. Absolute values of the univariate Sk and **Ku** were within the range of −2 to +2 and were interpreted as normally distributed.

The second order factor loadings and **its** significance are reported in Table 5. Each of the first factors strongly loaded onto the second order factor, as follows: Aroma (0.59), **Mouth-feel** (0.71) and Flavor (0.74), and are highly significant since their respective *p*-value is lower than 0.01. The results showed that the first order three factors could be better explained by a single **second-order** factor.

The loadings for the three **first-order** factors and its significance is presented in Table 6 shows. As can be seen, all the factor loading values are above 0.5 and are highly significant since their respective *p*-value is lower than 0.01, indicating that all items are meaningful in measuring the respective component (**first-order** factor).

Thus, the first order factor Aroma is characterized by the descriptors "floral aroma", "peach aroma" and "pineapple aroma", **Mouth-feel** is characterized by the descriptors "texture", "persistent", "body", "balance", and "intensity" the descriptors that characterized Flavor are "acid", "alcoholic sensation" and "freshness" (Figure 4-C).

4. Discussion

Whenever a product has multiple flavor and texture characteristics that are anticipated by consumers to be at specific and consistent intensities, the most comprehensive way of ensuring that all of these meet their targets is to use a trained panel to conduct frequent descriptive profiling sessions. In our work, from thirty-six employees of Aveleda S.A. initially recruited, only 21 candidates attended the first session for selection/training. However, from those 21, just in eleven of them the success rate in the ranking order tests of basic tastes and in the **Mouth-feel** sensation of astringency reached 70% of correct answers. Compared to previous studies (Monteiro, 2012), this percentage is quite satisfactory. The tasters also performed triangular tests with a success rate of 100%. As a result, the final panel of tasters consisted of eleven tasters. According to Meilgaard et al. (1991) and Stone & Sidel (1985), the number of panelists is dependent on the type of testing required. Descriptive panels, such as ours, may consist of five or more panelists (Lawless & Heymann, 2013).

Afterward, the tasters were subjected to intensive training (taste, color, and olfactory perception training). **Which** relates to the ranking order tests, success rates from 64% (astringency) to 82% (sour taste) were achieved. Good results were also obtained in the color and olfactory perception training. For instances, with a success rate of 100% of correct answers, the panelists identify fruity and herbal aromas. According to Elortondo et al. (2007), the desirable success rate for this kind of test is 75%. In the work described by Hough et al. (1995), candidates with 65% or more correct responses were accepted and candidates with less than 50% correct responses were rejected. Candidates with success rates between 50% and 65% should repeat the test, this time requiring a success rate of over 70%. However, the study presented by Monteiro (2012) already revealed results very similar to those obtained in our work, thus, it can be concluded that the success rate obtained is quite satisfactory.

When a trained tasting panel **agrees** and is able to sensory characterize a wine, analytical measurements are useful to characterize the space. More than a thousand flavor compounds have so far been identified (Francis & Newton, 2005). At present, volatile compounds can be analyzed under conditions very **close** to those which humans perceive aroma. Gas chromatography and mass spectrometry provide an effective tool for the odorant characterization of wines Chin et al. (2017). However, without sensory evaluation, the mere knowledge of the precise volatile composition of the wine aroma is inadequate to predict the flavor of the whole system as perceived by a trained sensory panel (Noble & Ebeler, 2002). In fact, aroma compounds can interact synergistically with one another and have masking or suppressing effects at above-threshold concentrations, or additive interactions at subthreshold concentrations (Francis & Newton, 2005).

González-Álvarez et al. (2011) established correlations between sensory and chemical data with the aid of multivariate statistical procedures and they were able to characterize the aroma of Godello variety white wines. García-Carpintero et al. (2011) through instrumental and sensory analysis studied Moravia Agria variety wines. As in our study, all aforementioned studies compared commercial wines that were made using different production methods, making it difficult to determine sensory characteristics unique to the region of origin, or even to the grape-variety. So, if at all possible, assessing differences between regions and/or sub-regions, or even determine the sensory profile of a wine from a specific region, should be done by producing wines with minimal oenological intervention, a single winemaker, and a single vintage. Still, with all these cautions, a lot of factors may have influence in wine sensory profile. Cadot et al. (2012) studied the relationship between the sensory profile of the wines and the ripening stage of the grape-berries. Results obtained suggest that the wine sensory quality, is linked to grape quality at harvest, reflected by sugar, tannins, and anthocyanin contents, demonstrating de importance of harvest date on the typicality of the wines. Parr et al. (2013) confirmed that vineyard location, row orientation, type of grape processing at harvest, and oenological manipulations provide means for influencing sensory profile and chemical composition of Sauvignon wines. More recently, Parpinello et al. (2015) verified that the quality of Sangiovese red wines was affected by the application of biodynamic "preparations" in the vines, influencing the sensory evaluation when comparing to organic viticultural management practices.

To identify the sensory profile structure of the 17 commercial monovarietal white wines from 3 cultivars (Loureiro, Alvarinho and Arinto) we adopted a second order factor analysis to test if there were underlying factors among the sensory attributes (first order) and if those latent factors loaded on the common sensorial profile factor (second order). **Factor analysis (FA) and structural equation modelling are multivariate statistical techniques that can be used to describe the covariance structure among the observed variables (sensory attributes) through a smaller number of variables, latent variables. Although both techniques can be used to identity the sensory profile structure of monovarietal white wines from the 3 cultivars, we decided to perform a SEM analysis because it allows to test theoretical propositions regarding how constructs are theoretical linked and the directionality of significant relationships. SEM, in comparison with FA, explicitly considers the measurement errors associated with the variables under study, defines causal or association relationships among the latent variables and can encompasses two sub-models, according to the relational structure between the variables: a measurement model and a structural model (Bollen, 1989; Maroco, 2014a). The measurement model is the CFA and defines how the latent variables are operationalized by the observed variables. As part of the process, factor loadings, variances, modification indexes, are estimated to choose the best indicators of latent variables prior to testing a structural model. The structural model displays the interrelations among latent variables. Moreover, in FA there is no criterion beyond interpretability against which to test the solution, i.e. there is no definite statistical test. The number of retained factors, the factor extraction technique and interpretability of the results involve subjective judgments of researchers; different researchers may come to a different solution.**

For all the monovarietal **wines** the final model **(SEM)** showed a good adequacy (Ho & Bentler, 1998; Byrne, 2001; Marôco, 2014a). This results allow us to say that in terms of a sensory lexicon, or a sensory profile, we can characterize de Loureiro wines as having "loureiro", "floral" and "mineral" aromas, they are "persistent", with a "soft sensation", "body" and "balance" in the mouth, and are likewise characterized by "vegetal", "citrus" and "tropical fruits" flavors. The sensory profile of Alvarinho wines is characterized by the attributes "floral", "citrus" and "apple" aromas; in terms of **Mouth-feel** they are "persistent", with "freshness", "body" and "balance", and also present "vegetal", "apple" and "tropical fruits" flavors. Arinto wines can be sensorially described as having "floral", "peach" and "pineapple" aromas, are "persistent", and also present in the mouth "texture", "body", "balance", and "intensity". In terms of flavor **is** "acid", with an "alcoholic sensation" and also with a fresh flavor "freshness".

There are some similarities between the sensory lexicons that can be used to better describe these wines. However, there are descriptors that specify each monovarietal wine. Loureiro wines present "Loureiro and mineral aromas"; Alvarinho wines present a "citrus" aroma and freshness in the mouth and Arinto wines have a distinctive fruity aroma (peach and pineapple) with an alcoholic, acid and fresh flavor.

As a result, although this work is of an exploratory nature, it highlights new interesting findings **of** the sensory characteristics of Vinho **Verde** monovarietal wines from Alvarinho, Arinto, and Loureiro grape varieties. Besides, it also shows that Structural Equation Modelling (SEM), is a good statistical tool to be used in sensory analysis data treatment, because **SEM explicitly considers the measurement errors associated with the variables under study, and can encompasses two sub-models, according to the relational structure between the variables: a measurement model and a structural model that allowed as to characterize the monovarietal wines according to their main sensory descriptors.**

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References

Abdi, H., Valentin, D., Chollet, S. & Chrea, C. (2007). Analyzing assessors and products in sorting tasks: DISTATIS, theory, and applications. *Food Quality and Preference, 18*, 627-640. https://doi.org/10.1016/j.foodqual.2006.09.003.

Bollen, K. A. (1989). *Structural equations with latent variables*. New York. NY: John Wiley & Sons, Inc.

Byrne, B. M. (2001). *Structural equation modeling with AMOS: Basic concepts, applications, and programming*. (2nd ed.) Lawrence Erlbaum, NJ.

Cadot Y., Caillé S., Thiollet-Scholtus M., Samson A., Barbeau G. & Cheynier V. (2012). Characterization of typicality for wines related to terroir by conceptual and by perceptual representations. An application to red wines from the Loire Valley. *Food Quality and Preference*, *24(1),* 48-58. https://doi.org/10.1016/j.foodqual.2011.08.012.

Cadot, Y., Caillé, S., Samson, A., Barbeau, G. & Cheynier, V. (2010). Sensory dimension of wine typicality related to a terroir by quantitative descriptive analysis, just about right analysis and typicality assessment. *Analytica Chimica Acta, 660*, 53-62. https://doi.org/10.1016/j.aca.2009.10.006

Chambers D. H., Allison. A. A. & Chambers. E. (2004). Effects of Training on Performance of Descriptive Sensory Panelists. *Journal of Sensory Studies, 19,* 486–499. Doi:10.1111/j.1745-459X.2004.082402.x

Chin, S. T., Eyres, G. T. & Marriott, P. J. (2017) Gas Chromatography-Mass Spectrometry in Odorant Analysis. In: Buettner A. (eds) Springer Handbook of Odor. Springer Handbooks. Springer, Cham. https://doi.org/10.1007/978-3-319-26932-0_17

Cordova, M. J., Studts, J.L., Hann, D. M., Jacobsen, P. B. & Andrykowski, M.A. (2000). Symptom structure of PTSD Following Breast Cancer. *Journal of Traumatic Stress, 13(2),* 301-319. Doi: 10.1023/A:1007762812848.

Corsi, A., Cohen, J. & Lockshin, L. (2013). Developing a Chinese lexicon for wine. *Wine & Viticulture Journal, 28(6)*, 66-68. https://search.informit.com.au/documentSummary;dn=156619940031036;res=IELHSS> ISSN: 1838-6547.

CVRVV. 2017. Retrieved from http://www.vinhoverde.pt/en/about-vinho-verde. Accessed 30-10-2017.

Drake, M. A., McInvale, S. C., Gerard, P. D., Cadwallader, K. R. & Civille, G. V. (2001). Development of a descriptive language for cheddar cheese. *Journal of Food Science, 66(9)*, 1422–1427. Doi:10.1111/j.1365-2621.2001.tb15225.x

Elortondo, F. J. P., Ojeda, M., Albisu, M., Salmerón, J., Etayo, I. & Molina, M. (2007). Food quality certification, an approach for the development of accredited sensory evaluation methods. *Food quality and Preference*, *18 (2*), 425-439. https://doi.org/10.1016/j.foodqual.2006.05.002

Etaio, I., Elortondo, F., Albisu, M., Gaston, E., Ojeda, M., & Schlich, P. (2008). Development of a quantitative sensory method for description of young red wines from Rioja Alavesa. *Journal of Sensory Studies, 23 (5)*, 631-655. Doi:10.1111/j.1745-459X.2008.00177.x

Fan, Y., Chen, J., Shirkey, G., John, R., Wu, S.R., Park, H., & Shao, C. (2016). Applications of structural equation modeling (SEM) in ecological studies: an updated review. *Ecological Process*, *5*, 19. https://doi.org/10.1186/s13717-016-0063-3

Francis, I., & Newton, J. (2005). Determining wine aroma from compositional data. *Australian Journal of Grape Wine Research, 11*, 114-126. Doi:10.1111/j.1755-0238.2005.tb00283.x

García-Carpintero, E., Sánchez-Palomo, E., Gómez, Gallego M. & González-Viñas, M. (2011). Volatile and sensory characterization of red wines from cv. Moravia Agria minority grape variety cultivated in La Mancha region over five consecutive vintages. *Food Research International, 44*, 1549-1560. https://doi.org/10.1016/j.foodres.2011.04.022

González-Álvarez, M., González-Barreiro, C., Cancho-Grande, B. & Simal-Gandara, J. (2011). Relationships between Godello white wine sensory properties and its aromatic fingerprinting obtained by GC-MS. *Food Chemistry, 129*, 890-898. https://doi.org/10.1016/j.foodchem.2011.05.040

Green, J., Parr, W., Breitmeyer, J., Valentin, D. & Sherlock, R. (2011). Sensory and chemical characterization of Sauvignon Blanc wine: influence of source of origin. *Food Research International, 44(9),* 2788-2797. https://doi.org/10.1016/j.foodres.2011.06.005

Hair, J.F., Black, W. C., Babin, B. J. & Anderson, R., E. (2009), Multivariate Data Analysis. Prentice Hall, New Jersey.

Ho, R. (1999). Factors influencing decisions to terminate life: Conditions of suffering and the identity of terminally. *Australian Journal of Social Issues, 34(1),* 25-41. Doi:10.1002/j.1839-4655.1999.tb01068.x

Hootman, R. C. (1992). *Manual on Descriptive Analysis Testing for Sensory Evaluation*. American Society for Testing and Materials eds. (pp. 1–3). Philadelphia. PA. USA.

Hopfer, H., Ebeler, S. & Heymann, H. (2014) *Comparison of Different Data Analysis Tools to Study the Effect of Storage Conditions on Wine Sensory Attributes and Trace Metal Composition*. Martinez-Mayorga K., Medina-Franco J. (eds) Foodinformatics. Springer. Cham.

Hough, G., Martinez, E., Contarini, A., Barbieri, T. & Vega, M. J. (1995). Selection of assessors based on their skill in identifying basic tastes in low concentration solutions. *Journal of sensory studies*, *10(1),* 1-14. Doi: 10.1111/j.1745-459X.1995.tb00001.x

Hu, L.-T. & Bentler, P. M. (1998) Fit Indices in Covariance Structure Modeling: Sensitivity to Underparameterized Model Misspecification. *Psychological Methods, 3 (4)*, 424-453. Doi: 10.1037//1082-989X.3.4.424

Ickes, C. M., Lee, S.-Y. & Cadwallader, K. R. (2017). Novel Creation of a Rum Flavor Lexicon Through the Use of Web-Based Material. *Journal of Food Science, 82*, 1216–1223. Doi:10.1111/1750-3841.13707

ISO 13299. Sensory analysis — Methodology — General guidance for establishing a sensory profile. 1st ed. *International Organization for Standardization*; Switzerland; 2016

ISO 13300 (2006). Sensory analysis — General guidance for the staff of a sensory evaluation laboratory—Part1: Staff responsibilities 1st ed. *International Organization for Standardization*; Switzerland.

ISO 3591 (1977). Sensory Analysis-Apparatus Wine-Tasting Glass. 1st ed. *International Organization for Standardization*; Switzerland.

ISO 6658 (2017). Sensory Analysis – Methodology – General Guidance. 3rd ed. *International Organization for Standardization*; Switzerland.

ISO 8589 (2007). Sensory Analysis - General Guidance for the Design of Test Rooms. 2nd ed. *International Organization for Standardization*; Switzerland.

Jolly, N. P. & Hattingh, S. (2001). A brandy aroma wheel for South African brandy. *South African Journal of Enology and Viticulture, 22(1),* 16–21. Doi: http://dx.doi.org/10.21548/22-1-2160

Lam, T.Y. & Maguire, D.A. (2012). Structural Equation Modeling: Theory and Applications in Forest Management. *International Journal of Forestry Research*, *vol. 2012*, Article ID 263953, 16 pages. Doi:10.1155/2012/263953.

Lawless, H. T. & Heymann, H. (2013). Sensory Evaluation of Food: Principles and Practices. Springer Science & Business Media, 827 p.

Lawless, L. J. R. & Civille, G. V. (2013). Developing lexicons: a review*. Journal of Sensory Studies, 28(4)*, 270–81. Doi:10.1111/joss.12050

Lee, K. Y. M., Paterson, A., Piggott, J. R. & Richardson, G. D. (2001). Origins of flavour in whiskies and a revised flavour wheel: a review*. Journal of Institute of Brewing 107(5)*, 287–313. Doi: 10.1002/j.2050-0416.2001.tb00099.x

Lurton, L., Ferrari, G. & Snakkers, G. (2012). Cognac: production and aromatic characteristics. In: Piggott J. editor. *Alcoholic beverages: sensory evaluation and consumer research*. (pp. 242–66). Oxford: Woodhead Publishing Limited.

MacCallum, R. C. & Austin, J. T. (2000). Applications of Structural Equation Modeling in Psychological Research. *Annual Review of Psychology*, *51(1),* 201-226. https://doi.org/10.1146/annurev.psych.51.1.201

Maitre, I., Symoneaux, R., Jourjon, F. & Mehinagic, E. (2010). Sensory typicality of wines: How scientists have recently dealt with this subject. *Food Quality and Preference, 21,* 726-731. https://doi.org/10.1016/j.foodqual.2010.06.003

Maltman, A. (2008). The Role of Vineyard Geology in Wine Typicity. *Journal of Wine Research*, 19(1), 1-17. Doi: 10.1080/09571260802163998

Marôco, J. (2014a). Análise de Equações Estruturais: Fundamentos teóricos, Software & Aplicações. ReportNumber, Lda.

Marôco, J. (2014b). Análise Estatística com o SPSS Statistics (sixth edition). ReportNumber, Lda.

Mc Ewan, J. A. & Schich, P. (1991/1992). Correspondence analysis in sensory evaluation. *Food Quality and Preference, 3*, 23-36. https://doi.org/10.1016/0950-3293(91)90020-F

Meilgaard, M., Civille, G.V. & Carr, B.T. (1991). *Sensory Evaluation Techniques*. 2nd ed., CRC Press, Inc. Boca Raton, FL.

Monteiro, B. (2012). *Seleção e treino de um painel de provadores para avaliação organolética de Vinhos do Porto*. Dissertação de mestrado em Enologia. Universidade de Trás-os-Montes e Alto Douro, Vila Real, 157 p.

Noble, A. & Ebeler, S. (2002). Use of multivariate statistics in understanding wine flavor. *Food Reviews International, 18,* 1-21. https://doi.org/10.1081/FRI-120003414

Noble, A. C., Arnold, R. A., Buechsenstein, J., Leach, E. J., Schmidt, J. O. S. & Stern, P. M. (1987). Modification of a standardized system of wine aroma terminology. *American Journal of Enology and Viticulture, 38(2)*, 143–146.

Noble, A. C., Arnold, R. A., Masuda, B. M., Pecore, S. D., Schmidt, J. O. S. & Stern, P. M. (1984). Progress towards a standardized system of wine aroma terminology. *American Journal of Enology and Viticulture, 35(2),* 107–109.

Parker, D. K. (2012). Beer: production, sensory characteristics and sensory analysis. In: Piggott J. editor. *Alcoholic beverages: sensory evaluation and consumer research*. (p 133–58). Oxford: Woodhead Publishing Limited.

Parpinello G., Rombolà A., Simoni M. & Versari A. (2015). Chemical and sensory characterization of Sangiovese red wines: Comparison between biodynamic and organic management. *Food Chemistry*, *167,* 145-152. https://doi.org/10.1016/j.foodchem.2014.06.093

Parr W., Schlich P., Theobald J. & Harsch M. (2013). Association of selected viniviticultural factors with sensory and chemical characteristics of New Zealand Sauvignon Blanc wines. *Food Research International, 53 (1),* 464-475. https://doi.org/10.1016/j.foodres.2013.05.028

Perrin, L., Symoneaux, R., Maitre, I., Asselin, C., Jourjon, F. & Pages, J. (2008). Comparison of three sensory Napping (R) procedure: case of methods for use with the ten wines from Loire valley. *Food Quality and Preference, 19(1),* 1-11. http://dx.doi.org/10.1016/j.foodqual.2007.06.005

Popper, R. & Heymann, H. (1996). Analysing differences among products and panellists by multidimensional scaling T. Naes. E. Risvik (Eds.). *Multivariate Analysis of Data in Sensory Science* (pp. 159-184). Elsevier. Amsterdam.

Spearman, C. E. (1904).General Intelligence, objectively determined and measured. *American Journal of Psychology, 15(2),* 201-292.

Stone, H. & Sidel, J. L. (1985). *Sensory Evaluation Practices*, Academic Press, New York, NY. p. 214.

Tu, Y.-K & Wu, Y.-C (2017). Using structural equation modeling for network meta-analysis. *BMC Medical Research Methodology, 104(17),* 1471-2288. https://doi.org/10.1186/s12874-017-0390-9

Vilela, A., Monteiro, B. & Correia, E. (2015). Sensory profile of Port wines: Categorical Principal Component Analysis, an approach for sensory data treatment. *Ciência e Técnica Vitivinícola, 30(1),* 1-8. https://doi.org/10.1051/ctv/20153001001

Volschenk, H., Van Vuuren, H. J. J. & Viljoen-Bloom, M. (2006). Malic acid in wine: origin, function and metabolism during vinification. *South African Journal of Enology & Viticulture*, *27(2),* 123-136. Doi: 10.21548/27-2-1613

Wright, S. (1921). Correlation and causation. *Journal of Agricultural Research, 20*, 557-585.

Wright, S. (1934). The method of path coefficients. *Annals of Mathematical Statistics, 5,* 161-215.

Zoecklein, B. W., Fugelsang, K. C., Gump, B. H. & Nury, F. S. (1995). *Wine Analysis and Production*. Chapmann & Hall, New York.

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Figure 1. Schematic representation of Vinho Verde sub-regions.
Figure 2. Schematic representation of Vinho verde wine colors. Glasses from 1 to 3 are representative of the usual Vinho verde wine colors and glasses 4 and 5 are representative of wines with colors defects such as wine-oxidation.
Figure 3. White wine aroma wheel retrieved from: http://merchantsfinewine.com/faq-items/wine-aroma-wheels/.

Figure 4. Percentage of tasters and respective perception thresholds for sweet (A), sour (B) and astringency perception (C).

Figure 5. Schematic representation and values of the standardized factor weights and the individual reliability of each of the items in the final second order CFA model for the sensory profile of monovarietal Loureiro (A), Alvarinho (B) and Arinto (C) wines.

Table 1 – Compounds and their concentrations used in the ranking order and triangular test. Solutions were prepared in mineral water, at room temperature.

Compound	Associated aroma	Concentration (ranking order test)				Concentration (triangular test)
		C1	**C2**	**C3**	**C4**	
Linalool (µg/L)	Lavender	80	100	150	200	-
Acetic acid (g/L)	Vinegar	0.8	1.1	1.65	2.2	0.75
Acetaldehyde (mg/L) Ethyl acetate (g/L) TCA (2,4,6-tricloroanisol) (ng/L)	Rotten-apples Glue Cork taint	100 0.08 1	125 0.16 4	150 0.32 8	200 0.48 16	50 150 5.5

Table 2 – Hue and color intensity citations of four Vinho verde wine samples (%) after sensory evaluation by the eleven tasters.

Wine number	Hue	(%) citation	Color intensity	(%) citation
1	Straw yellow	56.2	Slightly intense	81.2
2	Golden	56.2	Slightly intense	68.7
3	Yellow green	68.7	Slightly intense	87.5
4	Amber	81.2	Slightly intense	68.7

Table 3 - Success rate of the panelists for natural aromas discrimination.

Aromas	**Associated image**	**% correct citations**	**Aromas**	**Associated image**	**% correct citations**	**Aromas**	**Associated image**	**% correct citations**
Honey		86.7	Linden		73.3	Almond		86.7
Chamomile		60.0	Laurel		73.3	Fresh herb		100.0
Apple		86.7	Mango		86.7	Wood		86.7
Orange blossom		46.7	Lavender		66.7	Jam		53.3
Lemon		100.0	Banana		100.0	Vanilla		46.7
Melon		100.0	Lemon balm		46.7	Pineapple		66.7
Hazelnut		86.7	Grapefruit		40.0	Peach		93.3
Candied fruit		20.0	Walnut		86.7	Flowers		86.7

Table 4. Descriptive statistics (M±SD) and univariate normality measures (Sk and Ku).

wines	Descriptors	M±SD	Sk	Ku
Loureiro	floral aroma	2.62±1.19	0.13	-1.05
	loureiro aroma	2.16±0.89	0.30	-0.49
	mineral aroma	1.74±0.85	0.71	-0.75
	persistent	2.75±0.90	-0.07	-0.22
	soft sensation	2.68±1.01	-0.16	-0.92
	body	2.62±0.88	0.11	-0.55
	balance	2.68±0.92	-0.27	-0.73
	vegetal flavor	2.43±1.05	0.14	-1.03
	citrus flavor	2.71±1.11	-0.11	-0.89
	tropical fruits flavor	2.27±1.04	0.37	-0.62
Alvarinho	apple aroma	2.90±0.95	0.16	-0.64
	balance	3.16±0.74	-0.68	0.40
	body	3.15±0.89	-0.84	-0.03
	sweet	2.77±1.08	0.11	-0.81
	persistent	3.11±0.84	-0.40	-0.54
	freshness	3.28±0.89	-0.11	-0.30
	tropical fruits aroma	2.96±1.05	-0.22	-0.65
	floral aroma	2.80±1.12	-0.27	-0.95
Arinto	floral aroma	2.32±1.12	0.58	-0.32
	peach aroma	1.95±1.04	1.25	1.42
	pineapple aroma	2.11±1.09	0.54	-0.582
	texture	2.76±0.89	0.37	0.06
	persistent	2.56±0.79	-0.28	-0.36
	body	2.54±0.80	0.41	0.25
	balance	2.71±0.85	-0.31	-0.44
	intensity	2.85±0.83	-0.39	-0.33
	acid	3.09±1.03	-0.04	-0.46
	alcoholic sensation	2.76±0.96	0.23	-0.33
	freshness	3.15±1.05	-0.17	-0.79

Table 5. Maximum likelihood estimates and it significance in SEM models of Loureiro, Alvarinho and Arinto wines.

Wines	First order factor	Second order factor	UC	SC	SE	CR	*P*
Loureiro	Aroma	Sensory Profile	0.818	0.993	0.093	8.765	0.001
	Mouth-fell	Sensory Profile	0.603	0.818	0.078	7.771	0.001
	Flavor	Sensory Profile	0.664	0.996	0.085	7.799	0.001
Alvarinho	Aroma	Sensory Profile	0.450	0.520	0.116	3.899	0.001
	Mouth-fell	Sensory Profile	0.591	0.830	0.105	5.625	0.001
	Flavor	Sensory Profile	0.413	0.980	0.128	5.150	0.001
Arinto	Aroma	Sensory Profile	0.490	0.590	0.154	3.170	0.002
	Mouth-fell	Sensory Profile	0.460	0.710	0.115	4.021	0.001
	Flavor	Sensory Profile	0.680	0.740	0.163	4.199	0.001

UC: Unstandardized coefficients; SC: Standardized coefficients; SE: Standard error. CR: Critical ratio and *p*-value.

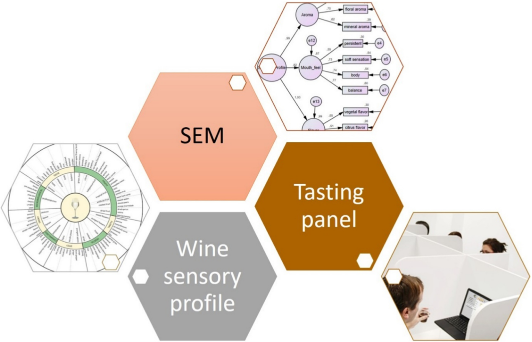
Table 6. Unstandardized and standardized maximum likelihood estimates and its significances in SEM models of Loureiro, Alvarinho and Arinto wines.

Wines	Descriptors	UC	SC	SE	CR	*P*
Loureiro	floral aroma	1*				
	loureiro aroma	0.461		0.100	4.625	0,01
	mineral aroma	0.642	0.622	0.099	6.510	0,02
	persistent	0.669	0.548	0.108	6.176	0,001
	soft sensation	1*				
	body	0.874	0.736	0.107	8.176	0,001
	balance	0.962	0.772	0.113	8.502	0,001
	vegetal flavor	0.856	0.547	0.154	5.554	0,001
	citrus flavor	0.854	0.513	0.162	5.266	0.001
	tropical fruits flavor	1*				
Alvarinho	floral aroma	0.673	0.523	0.174	3.875	0.001
	citrus aroma	1*	0.771			
	apple aroma	0.594	0.556	0.149	3.988	0.001
	persistent	0.906	0.770	0.111	8.172	0.001
	freshness	0.736	0.590	0.121	6.605	0.001
	body	1*	0.805			
	balance	0.825	0.800	0.097	8.486	0.001
	vegetal flavor	0.916	0.594	0.200	4.573	0.001
	apple flavor	0.624	0.387	0.185	3.379	0.001
	tropical fruits flavor	1*	0.644			
Arinto	floral aroma	1*	0.745			
	peach aroma	0.757	0.608	0.293		0.01
	pineapple aroma	0.625	0.480	0.269	2.329	0.02
	texture	0,86	0.632	0.154	5.585	0,001
	persistent	0,786	0.648	0.137	5.743	0.001
	body	1*	0.823			
	balance	0.741	0.574	0.148	5.007	0.001
	intensity	0,998	0.788	0.141	7.088	0.001
	acid	0.659	0.595	0.171	3.866	0.001
	alcoholic sensation	0.41	0.400	0.139	2.956	0.003
	freshness	1*	0.893			

UC: Unstandardized coefficients; SC: Standardized coefficients; SE: Standard error. CR: Critical ratio.*reference point.

Highlights

- From twenty one candidates, only half were selected for the tasting panel.
- A second order factor analysis model was developed for each grape-variety wine.
- There are similarities between the sensory lexicons of the monovarietal wines.
- SEM is a worthy statistical tool to be used in sensory analysis data treatment.



Graphics Abstract

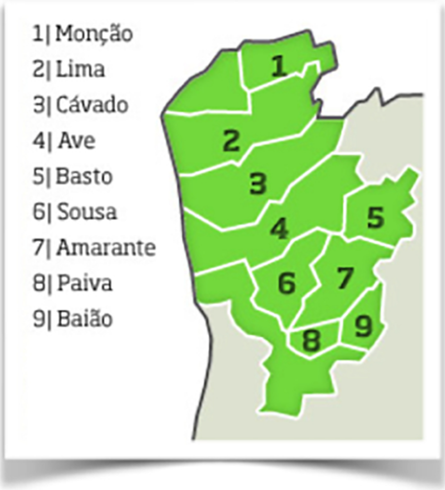

1| Monção
2| Lima
3| Cávado
4| Ave
5| Basto
6| Sousa
7| Amarante
8| Paiva
9| Baião
1
2
3
4
5
6
7
8
9

Figure 1


1
2
3
4
5
Lemon yellow
Greenish yellow
Yellow Straw
Golden/ambar
Ambar/oxidized

Figure 2

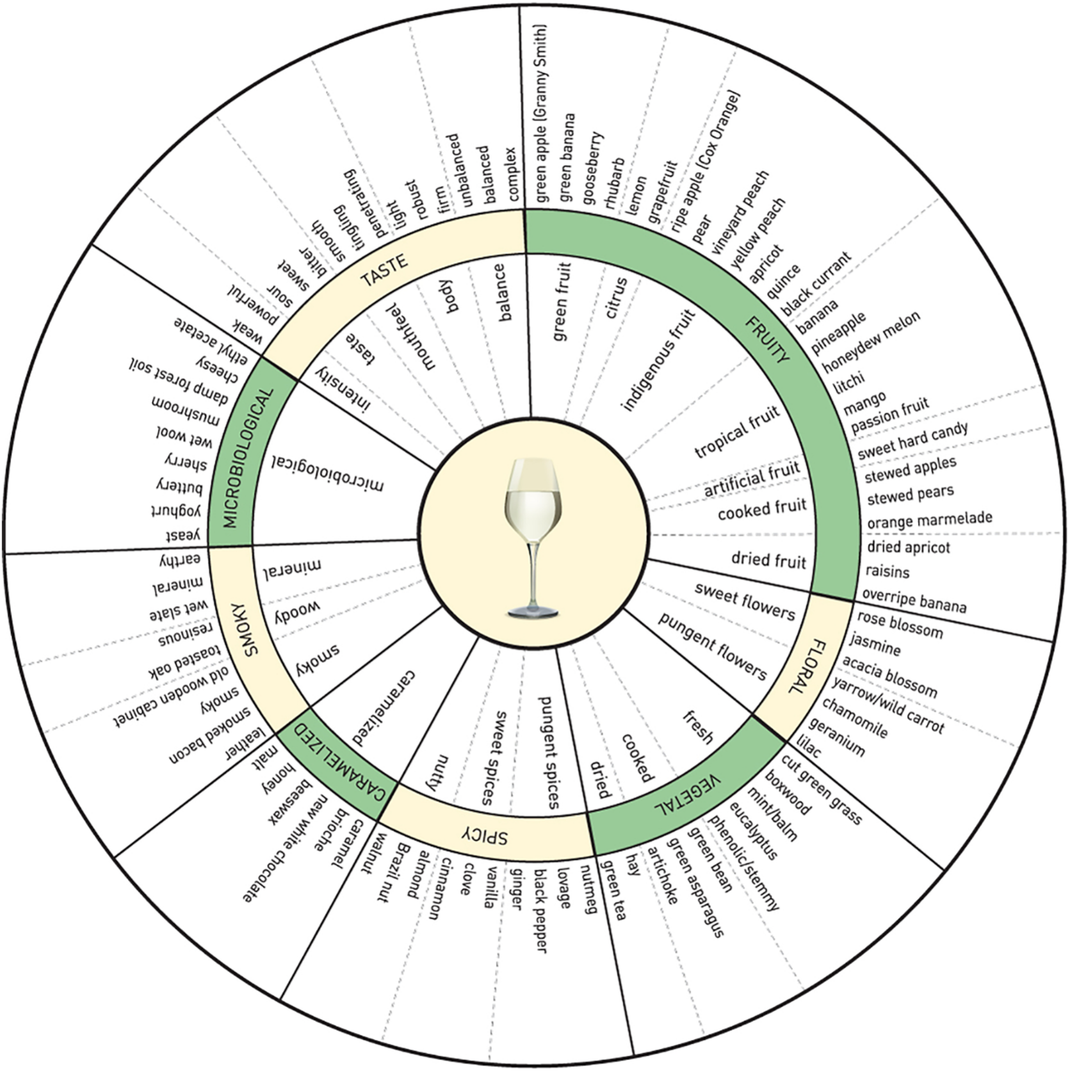
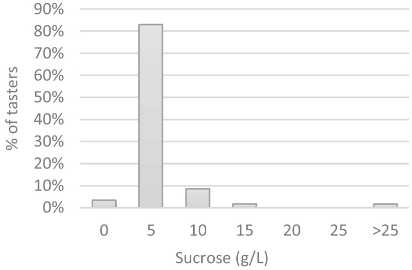
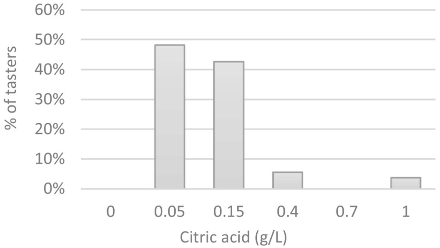

TASTE
FRUITY
FLORAL
VEGETAL
SPICY
CARAMELIZED
SMOKY
MICROBIOLOGICAL
balance
body
mouthfeel
taste
intensity
green fruit
citrus
indigenous fruit
tropical fruit
artificial fruit
cooked fruit
dried fruit
sweet flowers
pungent flowers
fresh
cooked
dried
pungent spices
sweet spices
nutty
caramelized
smoky
woody
mineral
microbiological
complex
balanced
unbalanced
firm
robust
light
penetrating
tingling
smooth
bitter
sweet
sour
powerful
weak
green apple (Granny Smith)
green banana
gooseberry
rhubarb
lemon
grapefruit
ripe apple (Cox Orange)
pear
vineyard peach
yellow peach
apricot
quince
black currant
banana
pineapple
honeydew melon
litchi
mango
passion fruit
sweet hard candy
stewed apples
stewed pears
orange marmelade
dried apricot
raisins
overripe banana
rose blossom
jasmine
acacia blossom
yarrow/wild carrot
chamomile
geranium
lilac
cut green grass
boxwood
mint/balm
eucalyptus
phenolic/stemmy
green bean
green asparagus
artichoke
hay
green tea
nutmeg
lovage
black pepper
ginger
vanilla
clove
cinnamon
almond
Brazil nut
walnut
caramel
brioche
new white chocolate
beeswax
honey
malt
leather
smoked bacon
smoky
old wooden cabinet
toasted oak
resinous
wet slate
mineral
earthy
yeast
yoghurt
buttery
sherry
wet wool
mushroom
damp forest soil
cheesy
ethyl acetate

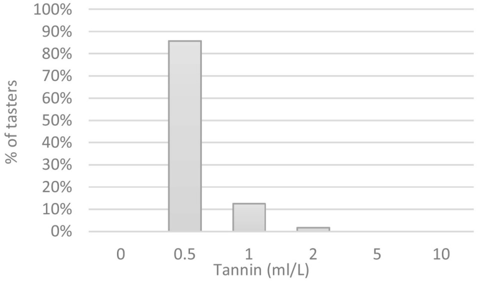
Figure 3


90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% of tasters
0
5
10
15
20
25
>25
Sucrose (g/L)

A

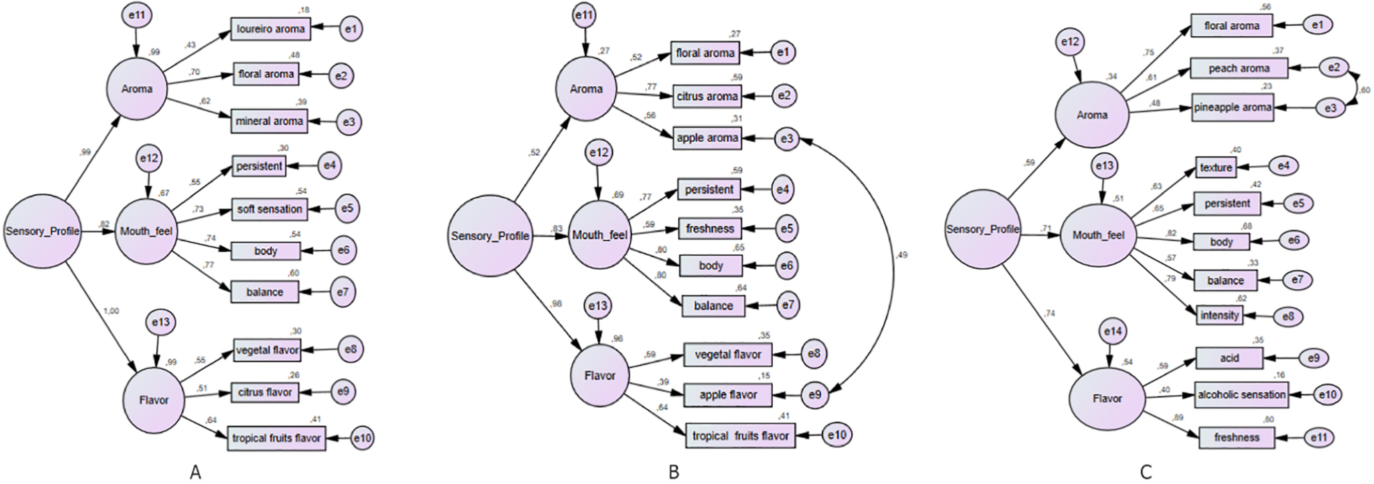

60%
50%
40%
30%
20%
10%
0%
% of tasters
0
0.05
0.15
0.4
0.7
1
Citric acid (g/L)

B


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% of tasters
0
0.5
1
2
5
10
Tannin (ml/L)

C

Figure 4



e11
loureiro aroma
floral aroma
mineral aroma
Aroma
e12
persistent
soft sensation
body
balance
Mouth_feel
Sensory_Profile
e13
vegetal flavor
citrus flavor
tropical fruits flavor
Flavor
A
floral aroma
citrus aroma
apple aroma
persistent
freshness
body
balance
vegetal flavor
apple flavor
tropical fruits flavor
B
floral aroma
peach aroma
pineapple aroma
texture
persistent
body
balance
intensity
acid
alcoholic sensation
freshness
C

Figure 5