Electronic Noses and Electronic Tongues as a Robust Approach to the Quality Assessment of Grape Wine – a Review

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Abstract - *The aroma and quality of wine can be assessed by different analytical methods for the identification of the organoleptic properties of the products. The classical chemical analysis methods such as spectrophotometry, gas and liquid chromatography, mass spectrometry and nuclear magnetic resonance, are highly reliable and suitable for these purposes, but these analytical techniques are of high cost and render themselves to be rather impractical when it comes to feasibility. Currently human organoleptic senses are used to analyze wines. Highly competent human panels evaluate the flavor profiles, in order to determine the quality. The practical application of human senses for assessment is severely limited by the fact that our senses are subjective and get tired easily – hence being inefficient. The classification of wine is extremely important on the grounds of economic value and annexed sociocultural reasons. Wine is primarily classified for the assignment of a trademark such as protected geographic indication (PGI), controlled denomination of origin (CDO) and protected designation of origin (PDO). In light of the same, analytical systems coupled with pattern recognition methods gauge and analyze the quality and origins of wines; and thus as a consequence, protect the trademark and prevent their abuse and adulteration.*

Keywords: Electronic nose, Electronic tongue, Wine Quality Assessment, Digital Flavor Profiling, Biosensors

1. Introduction

Wine is one of the most familiar alcoholic beverages and consist of numerous components in the hundreds in different ranges of concentrations. The most common and important sensory techniques is the sensory evaluation by a trained panel of human experts, as it is directly related to the organoleptic characteristics and quality of wines. Such an evaluation is carried out throughout the elaboration process from the analysis of the grapes to the evaluation of the final product. Only in a few cases are food and wine tasters used, under controlled conditions, as analytical instruments [1]. Such analytical panels are expensive and time-consuming, and they are not always available. The characterization of wines generally takes place by typical chemical methods involving liquid and gas chromatography or spectrophotometry, which is used to obtain data about the presence and concentration of certain components. Analyzing wines chemically is challenging due to the sheer complexity of the mixture, and the fact that even minuscule changes in the concentration of components can have a drastic effect on the organoleptic characteristics of the wine. Another thing to note is that the interactions between groups of compounds strongly influence the organoleptic characteristics than the individual components themselves. Wine analysis is in need of novel technologies and techniques capable of detecting multiple components simultaneously and their interactions and providing information about the sample as a whole instead of information about specific components present in it. Over the last few decades, a series of holistic methods have been developed to determine the quality of foods and beverages. In such methods, the instrumental signals (registered by Fourier-transform infra-red spectroscopy, mass spectrometry, Nuclear Magnetic Resonance, chromatography, or signals provided by an array of sensors) are processed with the help of pattern recognition software to obtain fingerprints of each sample, which can be discriminated and or classified. There isn't any need for the separation of the complex mixture into its constituent compounds. Complex mixtures don't have any need to be separated into the individual components that they are comprised of. The ability of mammals to identify food through their senses was the inspiration behind such holistic approaches [2].

Electronic noses – e-nose (e-N) and electronic tongues – e-tongue (e-T) are two such holistic approaches that are based on arrays of electronic sensors. E-Sensors have been utilized by the food industry for analyzing odor and taste to evaluate the quality of products ranging from wine, fish, meat, beer, milk to water. The main objective of this article is to state and reiterate the functions and applications of e-T and e-N in the wine industry.

2. Multi-Sensor Systems Used in Electronic Noses

The electronic nose is an instrument which comprises of an array of electronic chemical sensors capable of recognizing simple and complex odors [3], [4]. The purpose of these instruments is to register the signals produced by the mixture of gases and thus analyze the aroma profiles as a mammalian nose does, and then comparing the pattern of responses produced by different samples. Their main application pertains to the analysis of wine not exclusive of quality and aging control, and the detection of fraudulence, among others [5]. It must be noted that wine analysis, given its complexity isn't a completely solved problem. Even the minutest differences in composition between different wine samples can lead to varying results, and the presence of water and ethanol interfere in the sensor responses [6]. Bearing this in mind, there is new research being directed towards the development of arrays of sensors with increased sensitivity and improved quality in reproduction. Resistive sensors based on Metal Oxides – MOX that are doped and metal–oxide–semiconductor field-effect transistor - MOSFET are sensing units that are most popularly used in analyzing arrays for wine analysis [7]. Conducting polymers - CP are also utilized in resistive wine analyzing sensors despite their high water sensitivity [8]. Arrays consisting of quartz microbalance – QMB sensors, surface acoustic wave – SAW sensors and optical sensors have also been successfully used in the analysis of wine. On account of the high water and ethanol sensitivity of resistive sensors, the sampling techniques used must be not only to collect a representative headspace of the ethanol in the sample but also to eliminate, or at least to decrease the concentration of water in the volatile mixture. The sampling techniques commonly used in electronic noses for wines are inclusive of: Purge and Trap – P&T, Solid Phase Micro Extraction – SPME and Static Headspace - SH. In solid phase micro extraction, absorbent resins that have low affinity towards water and ethanol are used to collect the volatile components present in the headspace of the sample through adsorption. Upon adsorption the volatile components are released by applying a temperature program and injecting them in the sensor chamber.

3. Multi-Sensor Systems Used in Electronic Tongues

The advent of electronic noses paved the way for the development of multi-sensor systems for liquid analysis. Such instruments were called taste sensors or electronic tongues. Electronic tongues can use arrays of sensors based on a variety of principles such as electrochemistry optics and mass, but electrochemical sensors such amperometric, voltametric, or impedimetric sensors potentiometric are the most widely used to design e-tongues [9], [10]. In potentiometric sensor arrays, the potential across a selective membrane prepared from different materials such as lipidic, polymeric, etc is measured. This created potential at the interphase is dependent on the interaction of the electrode with the solution, which in itself is dependent on the chemical compounds present in the analyzed solution [11]. Arrays of Light Addressable Potentiometric Sensors – LAPS, micro Ion Selective Electrodes – μISE or miniscule Ion Selective Field Effect Transistors – ISFETS have also been developed using silicon planar technology [12]. Multi-sensor systems involving potentiometers have been deployed for the evaluation of wines' organoleptic properties [5], [13]. Impedimetric sensors based multi-sensor systems modified with organic materials such as conductive polymers, carbon nanotubes, phthalocyanines or perylenes are also utilized in wine analysis [14]. In amperometric and voltametric sensors, a bias voltage is exerted and redox activity compounds are either oxidized or reduced at their characteristic voltage [15]. Amperometric or voltametric sensors based multi-sensor systems are growing in popularity in wineries because they can detect redox species such as phenols [16]. Conditions of ecperiments can be adjusted by varying the excitation functions for example: pulse voltammetry, square wave voltammetry or cyclic voltammetry, or by establishing specific ranges of working conditions. Apart from this, they can also be prepared using a variety of chemical modifiers with electro-catalytic properties such as carbon nanotubes, nanoparticles, conductive polymers or phthalocyanines among others, thus improving the sensitivity. The electrode and the solution interactions simultaneously improve the selectivity of the electrodes to a great extent. Some of such interactions include:

(i) The oxidizing or reducing character of the solution that is able to modify the oxidation potential of the electrode material.
(ii) The electro-catalytic activity of the electrode material that can oxidize compounds dissolved in the test solution.
(iii) The potential of hydrogen of the solution can protonate or deprotonate the electrode.
(iv) The concentration of ions present in the solution and their nature of diffusion inside the sensing layer to maintain the electro-neutrality [17], [18].

Multi-transduction systems that are composed of different measurement types are sought after in electronic tongues [19]. The latest frontiers in the field of electronic tongues is the inclusion of biosensors with specificity toward certain compounds in the array. These instruments are known bio-electronic tongues and are gaining popularity in wineries as they provide global information about the wine similar to a classical arrays while also simultaneously producing data about particular compounds which is all made possible due to the specificity of the biosensors [20], [21]. For example biosensors containing phenol-oxidases such as peroxidase, laccase or tyrosinase are used to detect phenols, whereas glucose oxidase or fructose dehydrogenase are used for sugar detection [22], [23]. When designing biosensors arrays, it is necessary to keep in mind that each enzyme has specific functional conditions [24].

4. Multivariate Data Treatment

The response combinations of the sensor arrays are not specific for a certain compound, but rather dependent on certain characteristics of the samples by means of pattern recognition techniques. Sequentially four steps are followed:

i. Pre-processing of signals:
The pre-processing of signals include drift compensation, scaling, and the extraction of representative parameters.
ii. Reduction of dimensionality:
The dimensionality reduction step projects the initial feature onto a space of lower dimensional. This is usually carried out by means of a non-supervised technique, such as principal component analysis (PCA). PCA can be used to discriminate between samples with different organoleptic characteristics.
iii. Prediction:
The prediction problems such as regression and classification are solved by the resulting low-dimensional feature vector.
iv. Validation

[25]

Classification tasks include the identification of an unknown sample and assigning it to a certain set of previously learned categorized samples. Typical classification models are linear discriminant analysis (LDA), Soft Independent Modeling of Class Analogy (SIMCA), Support Vector Machines (SVM), or Artificial Neural Networks (ANN). In regression tasks, the goal is to establish a predictive model using a set of independent variables such as sensor responses and a second set of variables that are the properties of the sample analyzed such as concentration and quality. Partial least square or

PLS is used for the regression model [26]. The organoleptic characteristics of wines are dependent on the how the wine is chemically composed, which in itself is primarily dependent on the grape variety, the crushing methodology used, and the chemical reactions that take place during wine making or during wine aging in barrels as well as bottles. Electronic noses and electronic tongues are utilized in the quality control of wines at different production stages right from the quality evaluation of the grapes that are going to be utilized for production to the analysis of the quality and organoleptic properties of the finished bottled product.

5. Utilization of Electronic Noses and Tongues in Various Aspects of Vinification

5.1. Assessment of the Quality of Grapes and Crushing

In oenology, the ripeness and quality of the grapes is established on the basis of their external appearance or the taste of the grape juices. The analysis of the sugar and phenolic content is also a common practice to establish the quality. Electronic tongues based on ion-sensitive field-effect transistor, or on voltametric sensors, have been used to discriminate grapes according to the variety or vintage of the grape [27], [28]. Biosensors are able to excellently establish correlations between the sugar and the phenolic content of mature grapes. After crushing, musts and skins are left in contact for a period of time in order to increase the concentration of phenols in the wine. A few techniques, such as micro-oxygenation or Flash release can be utilized to improve phenol extraction. An electronic panel, a combined system using an electronic nose, an electronic tongue, and color measurements is capable of detecting phenol concentration increases.

5.2. Monitoring the Fermentation

In the fermentation process of fresh grape extract, the sugars are converted into alcohol in non-aerobic conditions, thus producing wine. In white wines, only one fermentation (the alcoholic fermentation producing ethanol) is needed. In red wines, the alcoholic fermentation is followed by the malolactic fermentation, where malic acid is transformed into lactic acid. The process of fermentation is typically controlled by the measurement of physical parameters such as temperature and density [29]. In the malolactic fermentation process, the concentration of malic acid is monitored periodically. With fermentation being a turbulent process, the control by means of chemical sensors is quite difficult, due to the fact that the process produces changes in temperature that affect the performance of the sensors. However, a commercial electronic nose based on conducting polymers has been successfully deployed to monitor, on-line, the volatiles evolved during fermentation. Using IR spectroscopy with the combination of an electronic nose and electronic tongue, the kinetics of the fermentation process has been analyzed and correlations between the consumption of sugar and production of alcohol have been found [30]. Electronic noses can be installed in cellars with ease to monitor on-line, the changes occurring in tanks with the help of a sampling method that extracts the volatiles from the tanks where the wine is stored [31].

5.3. Monitoring the Aging of wines in Oak barrels

Red wines are aged in oak barrels before bottling for improvement in organoleptic characteristics. In many regions (or appellations), wines are classified according to the length of the aging in barrels. During the aging process, volatiles are released from lees. Additionally, small amounts of oxygen are diffused into the barrel through the pores present in the oak wood. The type of oak wood selected plays an important role because oaks from varying geographies or with varying degrees of toasting can induce varying flavors. The oxidative aging in barrels can be followed by aging in sealed bottles for the further improvement of the organoleptic characteristics of the wine. Electronic noses and electronic tongues can be used for the monitoring or recognition of the aging method. For instance, electronic noses based on metal-oxide gas sensors can discriminate between red wines vinified under the same conditions but aged in oak barrels of different geographic origins. To monitor aging, the measure of the variations in the volatile composition, measured periodically, can serve as a valuable tool. A potentiometric electronic tongue is capable of classifying Port wines of from ages 2 to 70 years and Madeira wines produced from varying grape varieties and aging durations [32], [33]. Similarly, voltametric electronic tongues have been utilized to discriminate between red wines aged in oak barrels of varying origins such as French, Lithuanian, or American with increasing toasting levels and to even bring to light the changes experienced in wines after an aging period of 3 to 6 months. In alternative aging methods, wines are matured by soaking chips of wood of varying dimensions in micro-oxygenated stainless steel tanks. These methods are devoid of the usage of expensive oak barrels and shorten the required aging time as well. Such practices are legal in many countries, but their use must be indicated on the label. Electronic noses and electronic tongues are efficient in the detection of alternative aging methods. In particular, a voltametric e-tongue was able to detect the use of alternative methods and to discriminate between the effect of the size and type of the pieces of wood. Upon bottling, the differences in the wines could not be told. [34].

5.4. Bottling

Natural cork stoppers are traditionally used in high-quality wines. Due to their porous nature, natural cork allows minute amounts of oxygen to diffuse into the wine. On the other hand, polymeric stoppers can be designed to have a certain porosity able to deliver controlled and reproducible amounts of oxygen into bottles. Recently, the effect of this nano-oxygenation has been successfully analyzed using a combined system of an e-nose formed by MOX sensors and an e-tongue formed by voltametric sensors. It was found to be that electronic tongues are more sensitive to the diffused oxygen than electronic noses. Both techniques when used in combination can detect not only the oxygen content, but also the polyphenolic level, which is in turn dependent on the oxidation state of wines, which in turn correlates to the organoleptic characteristics [35].

5.5. Evaluation of the Organoleptic Characteristics of the Final Product

One of the main applications of electronic noses and electronic tongues in the oenological sector is the of the quality evaluation of the final product. This includes the analysis of changes that occur over time (improving the bouquet), and also the detection of undesired changes due to cork damage or inappropriate storage. E-noses and e-tongues can also be a valuable tool for control-ling organisms in order to detect frauds that try to mislead the consumer, giving wrong information about the type of grape, geographical origin, etc. The variety of grape from which the wine is produced from plays a major role in the main organoleptic characteristics of the final product. On top of that, the differences in weather conditions, and the numerous viticulture techniques and manipulations that take part during the making of wine and aging. These differences in conditions are the reasons why the majority of wines are distinct in their own flavors and characteristics. The building of or rather the change in the organoleptic characteristics isn't restricted to the aging barrels alone but rather the process of aging continues in the bottle as well, improving the bouquet. MOX based e-noses can easily discriminate distinctive varietal flavors found in wines elaborated from different grape varieties, or grapes from different geographic origins or appellations. Electronic noses using mass spectroscopy in combination to chemometrics or arrays of SAW sensors are able to discriminate between different geographical origins [36], [37]. Amperometric or voltametric detectors combined with electronic noses are capable of classifying Italian wines with different regions of protected and specified geographical origins [38], [39]. The changes in the volatile mixture of grapes are subjected to varying pre-harvest and post-bloom treatments can also be detected using electronic noses [40], [41]. Other important aspects in viticulture, such as the effect of the canopy side or of sun-drying and dehydration, in the organoleptic characteristics of the final wine have also been evaluated with e-noses [41]. Regarding electronic tongues, arrays of potentiometric chemometric sensors have been extensively used for the discrimination of wines from the same geographic location and age, but from different vineyards [42]. Arrays of solid state potentiometric sensors are able to discriminate between different Italian white wines belonging to the appellation of Verdicchio [43]. Where as in the case of Madeira wines, the effect of age was found to be significant only for e-tongues [33]. Arrays based on ion-sensitive field-effect transistors can discriminate between wines elaborated from varying types of grape and vintage. Hybrid systems combining sensors such as ion-sensitive field-effect transistors, amperometric, redox potential, conductivity and can also characterize and classify monovarietal white wines according to the variety of grapes and origin on the basis of geography [44], [45]. Chemically modified Voltametric sensors with electro-catalytic materials, are utilized in the discrimination of wines owing to different Spanish appellations, grape types and aging length, and are able to monitor the changes occurring during the aging process of wine in barrels and bottles. The high number of different chemical modifiers used in voltametric arrays such as conductive polymers, carbon nanotubes, or phthalocyanines are worth noting due to the fact that they have led to a variety of arrays with different specifications. Gold interdigitated impedimetric sensors, modified with conductive polymers or lipids are capable of discriminating wines, according to the vintage or vineyard [46]. In wineries, the most common strategy is the usage of enzymes to detect phenol groups or sugars, as these compound groups influence the quality and organoleptic characteristics of wines to a great extent. Phenol specificity is achieved by the deployment of enzymes such as Tyrosinase or Lacasse both of which are phenol-oxydases that can be immobilized in carbon paste electrodes – CPEs, in the form of thin films or in graphite-epoxy electrodes [47]. Glucose oxidase, or fructose dehydrogenase, are two examples of enzymes that can be introduced in arrays using similar techniques.

5.6. Detection of Spoilage and Off-Odors

Wine quality of can be altered by the presence of certain unwanted chemical compounds formed during processing, fermentation or storage. The early detection of these off-odors is crucial to be able to undertake remedial actions that can correct the fault. Some of the major volatile compounds responsible for the presence of off-odors can be detected by electronic noses. They include acetic acid, ethyl acetate or sulfur compounds, or 4-ethylphenol and 4-ethylguaiacol caused by brettanomyces yeasts. Hampered corks produce off-flavors stemming from the presence of chlorinated compounds, such as 2,4,6-Trichloroanisole. Even a human nose can detect compounds even if in minute concentrations. For this reason, classical arrays of sensors cannot be used for this purpose and must be associated with chromatography [48]. Data treatment involving mass spectrometry can be utilized for this purpose [49]. Electronic tongues can also detect spoilage due to the presence of different compounds in wines. For instance, an electronic tongue composed of all solid state potentiometric sensors was able to monitor acetic acid levels in white wines [50]. An electronic nose combined with an array of potentiometric sensors has been used to monitor the spoilage of wines that was also followed by the titratable (total) acidity [51].

5.7. Detection of Frauds and Adulterations

Wine producers must follow the regulations indicated by their appellations and by national and international organisms. That does not stop unethical practices such as dilution with water, addition of substances, use of grapes from different regions, or using forbidden aging method from being carried out in order to make the wines more economical for producers. Electronic noses and electronic tongues can be a viable solution detecting such practices. As already mentioned in the previous paragraphs, electronic systems can be used to discriminate wines elaborated using different grapes and techniques. This capability can be used for quality control in cellars, but also by official organisms to certify the authenticity of the product, complementing the results obtained by traditional analytical techniques. Electronic noses can detect the presence of adulterants in wines such as methanol and ethanol [52]. Voltametric electronic tongues have been used in the detection of adulteration with ethanol and also the addition of other non-volatile adulterants such as sulfur dioxide, tartaric acid, tannic acid, sucrose and acetic acid. A dimensionally scaled down potentiometric electronic tongue has been able to detect hydrogen sulfide, sulfur dioxide, and acetic acid in artificial wines.

5.8. Assessment of Chemical Parameters

Due to the principle upon which they work, electronic noses and electronic tongues provide global information about a sample. Chemometrics is their main means of discrimination or classification of the samples. The obtained signals from sensors result from the interactions of the sensing layer with certain compounds or mixtures of compounds, correlations can be established between the responses of the sensors and the chemical composition of the sample. For this reason, chemometric tools, such as PLS regression can be used to establish mathematical models between the output of the array of sensors and the chemical data obtained by classical methods. Information about particular parameters can be obtained in this way [53], [26]. Moreover, upon calibration, electronic noses and electronic tongues can evaluate the concentration of many chemical parameters simultaneously. As stated before, e-noses based on MOX sensors or MS have been successfully used to quantify several volatile compounds, including acetic acid, ethyl acetate, eugenol, ethyl octanoate, sulfur compounds, or guaiacol. Electronic tongue responses can predict total and volatile acidity, total polyphenols, sugar content, pH, etc. impedimetric sensors Potentiometric, ion-sensitive field-effect transistor, amperometric, and voltametric sensors have been used for this task. For instance, potentiometric electronic tongues are capable of quantifying total and volatile acidity, pH, ethanol content, tartaric acid, sulfur dioxide, total polyphenols, and glycerol, with a precision of within 12% [54]. With the case of a different device, free and total sulfur dioxide, total acidity, ethanol, pH, and some phenolics have been accurately detected [26]. Multi-sensor systems that are in combination with potentiometric sensors prepared from glass membranes and plasticized PVC can be used to detect sinapic acid, tartaric acid, citric acid, formic acid and vanillic acid, trans-resveratrol, catechin and vanillin [33]. Arrays of miniaturized field-effect transistors and ion-sensitive field-effect transistors can also be used to measure pH, calcium, and potassium, necessary to control the tartaric stabilization of wines. Electrochemical micro sensors have been deployed in combination to other measuring systems to assess the chemical parameters concentration of wines [44], [22]. Amperometric and Voltametric sensors in particular are interesting for wine analysis due to their ability to detect redox activity compounds such as sulfites, polyphenols, and sugars. Examples found in the literature include electronic tongues based on simple metallic electrodes used to detect bisulfites and electronic tongues based on electrodes chemically modified with phthalocyanines that correlate well with up to 24 chemical parameters, including excellent correlations with the polyphenolic content (measured as total polyphenol index), acidity (measured as pH or total acidity), oxygen concentration, or antioxidant capacity. An array consisting of Electrochemical Quartz Crystal Microbalances – EQCM sensors modified chemically with phthalocyanines is able to detect antioxidants and sugars in musts using voltammetric and mass measurements simultaneously [55]. The antioxidant capacity of wines has also been evaluated using voltametric sensors modified with other electrocatalytic modifiers, such as nanoparticles, or sensors modified with phenol-oxidases (to detect phenols) or glucose oxidases to detect sugars. gas and liquid sensor Arrays based on porphyrins when used in combination were able to quantify sugar, acidity, pH, tartaric, malic and lactic acids, polyphenols, antocyans and ions (Ca, Mg, and K), alcoholic content, and sulfur dioxide, l-Malic acid, and total phenols index. The correlation coefficients and the limits of detection can be drastically improved when introducing biosensors into the array [56].

6. Correlations with Human Perceptions

The final quality of wines is related to human perceptions. It is usually evaluated by a panel of trained experts who are able to appreciate different attributes and give a score. Because electronic noses and electronic tongues are inspired by human senses, it is rational to expect that their outputs should be related to the scores given by a panel of experts. Unfortunately, the correlations with human perceptions are not easy to establish due to several factors. For instance, unlike the human systems, electronic noses and electronic tongues detect chemical compounds, whether they are species that have a taste or odor or are tasteless odorless or. In many cases, the intensity of the perception is not directly correlated with the concentration of a certain compound. Most of the times, compounds in a mixture have synergy amongst them and the resulting aroma or taste is not the addition of the smell or taste of the individual components. Finally, human taste is not only dependent on the chemical assay but rather the perceptions such as astringency, heat, viscosity, etc. that the mouth feel or flavors that contribute to the perception as well. And hence from the perception of an electronic nose, a complete description of the organoleptic properties is far-fetched. Perceiving the organoleptic properties of wines using electronic sensors is far-fetched due to the fact that wines are extremely complex mixtures and because panels of experts evaluate how pleasant a perception is. However, pleasure and perceptions are not linearly related to a compound or a family of compounds. In spite of the difficulties, using the appropriate array of sensors and PLS regression, it is possible to establish good correlations with sensory scores or with specific odors or flavors. An electronic nose combining 16 thin film-based sensors comprising of tin oxide has been used to recognize 29 typical aromas in white wine grouped into different families such as chemical, floral, fruity, microbiological, and herbaceous to detect the main aromas usually present in red and white wines. However, in general, sensory panels comprising of experts can identify aromas more efficiently than electronic noses [57]. It has been reported that results provided by an e-nose corresponded better to the scores given by the panel of experts than the predictions made by chromatography [6]. Good correlations have also been found with sensory scores and the outputs of arrays of potentiometric, amperometric, or voltametric sensors [54], [58], [26] [59], [60].

7. Combination of Electronic-Noses and Electronic-Tongues

The perception of flavor is based on both taste and aroma and can be analyzed using electronic noses and electronic tongues in combination. The simultaneous use of both systems increases the amount of information extracted from a certain sample, enhancing the prediction capabilities. Results indicative assays of the presence of certain compounds in wines, or to classify samples in good agreement with an expert sensory panel. For instance, an electronic nose and an electronic tongue based on porphyrins could be used to quantify ions (Ca, Mg, and K), sugar, acidity, pH, tartaric, malic and lactic acids, polyphenols, and antocyans in wines. Results demonstrate the capability of such systems to be trained according to data given by panels of tasters [61]. Combined e-noses and e-tongues have also been used to analyze the influence of corks in parameters related to the oxygen (diffused oxygen and antioxidants). Electronic noses and electronic tongues have also been combined with electronic eyes to form an electronic sensory panel that is capable of recognizing organoleptic characteristics of wines prepared using the same methodology, but from different grape varieties [39].

8. Conclusion and Future Trends

Electronic noses and electronic tongues consist of series of sensors which are non-specific with cross-sensitivity that respond to a wide variety of compounds. After appropriate evaluation training, they can serve their purpose in the wine industry to provide qualitative information about the sample, predict the concentration of certain compounds or detect certain organoleptic characteristics. The complete organoleptic description of a sample is not possible, but electronic noses and electronic tongues provide responses which are objective and independent of physiological conditions and personal preferences unlike human assays, and they also do not fatigue as human senses do. They have proved to be an indispensable tool for use in combination with classical analytical techniques to make key decisions regarding aging, harvesting, crushing or fermentation. Their main application binds to oenologists for the quality control of wines, but also by official organizations and bodies to detect fraudulent and illicit practices. A few authors in the scientific community have expressed their criticisms towards electronic noses and electronic tongues because the main problem with them is the lack of olfactory or taste sensors [62]. All criticism aside, electronic noses and electronic tongues are capable of detecting chemical compounds and this is vital for quality control purposes. There are numerous ongoing developmental works and researches in the field of electronic sensors to develop new sensors with improved selectivity, and the performances of multisensor systems has also improved greatly, particularly with the use of biosensors. Validation is also a major concern in electronic noses and electronic tongues [63]. With wines, the concern of weak validations is particularly important, because wines change with time, and their quality depends on numerous odd conditions. So, it is very difficult to have a large number of well characterized samples to carry out an appropriate training. The way to solve this problem is to construct international databases. In the field of electronic tongues applied to wine, several institutions are currently working on the construction of a database that would help to improve the quality of validations [64]. Future strategies will also include the design of arrays formed by new materials with improved selectivity and sensitivity, in many cases linked to nanotechnology or with biosensors. Efforts have to be made to introduce these instruments in cellars and in the list of recommended analytical tools established by the National and International Commissions.

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