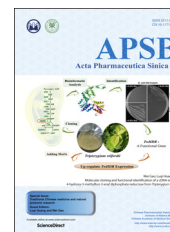




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REVIEW

New sensor technologies in quality evaluation of Chinese materia medica: 2010–2015



Xiaosu Miao, Qingyu Cui, Honghui Wu, Yanjiang Qiao, Yanfei Zheng*,
Zhisheng Wu*

School of Chinese Materia Medica, Beijing University of Chinese Medicine, Beijing 100102, China

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Abstract New sensor technologies play an important role in quality evaluation of Chinese materia medica (CMM) and include near-infrared spectroscopy, chemical imaging, electronic nose and electronic tongue. This review on quality evaluation of CMM and the application of the new sensors in this assessment is based on studies from 2010 to 2015, with prospects and opportunities for future research.

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*Corresponding authors. Tel.: +86 104738621; fax: +86 10 84738661.

E-mail addresses: yanfei_z@163.com (Yanfei Zheng), wzs@bucm.edu.cn (Zhisheng Wu).

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1. Introduction

Quality evaluation of Chinese materia medica (CMM) is targeted at safety and effectiveness. Rapid analysis in quality control is focused on holistic characterization and measurement of active ingredients, and is of significant public concern. However, because of the diversity of ingredients and the multi-targets effects, the quality standard of CMM has not been universally acknowledged. A low quality standard also impedes the pace of modernization and internationalization of CMM. Thus, it is necessary to establish a reasonable and effective quality evaluation system. So far the development of quality assessment of CMM has gone through four stages: off-line analysis, on-line analysis, in-line analysis and on-site analysis¹. With the development of analytical methodology, high performance liquid chromatography (HPLC), gas chromatography (GC) and other methods have been increasingly utilized. Although these conventional methods can provide accurate identification and quantitation of active pharmaceutical ingredients, they are unable to provide information about the spatial distribution of individual components, even making it difficult or impossible to trace the source of failures or anomalies. In this case, a new trend in the sensor field is to couple multidimensional sensors with advanced information processing strategies, such as near-infrared (NIR), electronic nose (EN), electronic tongue (ET) and chemical imaging (CI). These new sensors are fast, simple, and inexpensive, and have become an effective method for identification and quality control of CMM².

At present, the new sensors play a very critical role in the field of pharmaceutical analysis with regard to the evaluation of safety and effectiveness of CMM. A growing number of researchers have referred to the sensors, including the NIR, EN, ET, CI. Here we will review changes to quality evaluation of CMM and the application of the new sensors from 2010 to 2015. Furthermore, the development of NIR, CI, EN and ET for qualitative and quantification analysis of CMM will be discussed. Finally, the limitation of these new sensors and the future directions for research will be considered.

2. NIR spectroscopy

Online NIR sensors (NIRS), one of the most important technologies in the rapid quality evaluation of CMM, have become highly popular and are widely used in the fields of process control including extraction, concentration, alcohol precipitation and purification. Moreover, with the rapid development of information technologies and especially developments in chemometrics, online NIR sensors have increasing applications in quality analysis abroad³⁻⁵.

2.1. Qualitative analysis of CMM

2.1.1. Identification and authentication

Identification and confirmation of the authenticity of CMM has mainly relied on experience, microscopic identification, physical identification, and chromatographic identification. But now, NIRS can rapidly identify multiple chemical components and is updating these traditional methods. Gao et al.⁶ have characterized *Pinellia ternata* and spurious imposters. They reported that NIRS with cluster analysis was consistent with chromatographic analysis, providing a new method to confirm the authenticity of *Pinellia ternata* in a fast and stable method. Qu et al.⁷ collected *Colla corii*

asini from different sources and established a model to distinguish them by NIRS. Zhao et al.⁸ extracted component information of Rhubarb and used the Fisher classifier to confirm its authenticity. Shao et al.⁹ applied NIRS to qualitative recognition of extracts from *Anoderma lucidum* and *Coriolus versicolor*, providing a basic method for rapid identification of these extracts. Sun et al.¹⁰ investigated Semen Cuscutae and its adulterants. They generated data for the authentic product from NIRS, choosing the optimum wavebands with the highest precision, and were able to make distinctions between three different pharmaceutical materials.

2.1.2. Determination of geographical origins

It has been proposed that the main components of CMM, even when from the same location, are influenced by different factors (for example, climate and growth conditions), which leads to variations in quality. Compared with the traditional methods, NIRS can authenticate the CMM regardless of origin.

To investigate the effect of geographical origin on pharmaceutical content, many researchers have utilized NIRS. For example, Guo et al.¹¹ established a NIRS method for the identification of *Citri reticulata*, which is well known as a non-destructive and green technology. Additionally, Wang et al.¹² measured and analyzed the NIR data of 102 batches *Cordyceps sinensis* samples from different habitats. In this case, the accuracy of the results has reached 100%. Liu et al.¹³ gathered 269 batches of *Angelicae Radix* and 350 batches of *Salvia miltiorrhiza* to characterize these samples by geographical origins. It suggested that the accuracy of cross validation was 99% and 95%, respectively. Sun et al.¹⁴ assembled the Cortex *Phellodendri* and its adulterants. They established a discriminant model which has been verified by a triple cross-validation method. Recently, Bai et al.¹⁵ built an analysis method on NIRS of *Rehmanniae Radix* from three producing fields, offering a new technology for the further identification.

2.1.3. Characterization of processing

Processing is responsible for the change of chemical components under the theory of CMM. After processing, these changes can be identified by NIR. For instance, when raw *Rehmanniae Rhizoma* was processed, the content of sugar should differ according to the processing time. With the help of NIRS, Wang et al.¹⁶ developed a new method for identification of *Rehmanniae Rhizoma* based on the number of steamed treatment hours, and found that samples could be separated perfectly.

To process the *Agastache rugosus*, Cai et al.¹⁷ designed three modes: ordinary drying method, shade-drying method and heating-drying method. By measuring the content of patchouli alcohol by NIRS, the best processing procedure could be determined. Ultimately, it turned out that the content of patchouli alcohol in the shade drying method was the best. Zhang et al.¹⁸ collected the extract samples and applied the NIRS to test the concentration of Dan phenolic acid B. Also, Ding et al.¹⁹ established a rapid method to monitor on-line the blending process of CMM powder. It was concluded that a miniature NIRS could be used to monitor the content of the constituents and the blending homogeneity of CMM powder in real time. Moreover, it could determine the endpoint of the blending process rapidly. Taken together, the method should be utilized to judge whether the physical state of a powder mixture conforms to the quality standard. Jin et al.²⁰ used the moving block standard deviation method and NIRS to identify the

end point of blending process, providing real-time data and instant feedback on the blending unit.

2.2. Quantification analysis of CMM

2.2.1. Detection of moisture

Proper moisture content is of great importance to maintain quality in CMM. Moisture influences the content of chemical components, whereas high moisture content could lead to deterioration. Therefore, how to measure moisture content effectively has aroused significant concern.

To establish a method for the quantitative determination of moisture content in *Pogostemon cablin* by NIRS, Cai et al.²¹ determined the moisture content of 142 samples by a vacuum-drying method. Wei et al.²² applied NIRS for the rapid detection of moisture in the drying process of *Paeoniae Alba Radix*. Additionally, Li et al.²³ developed a test of moisture content in *Eriobotrya japonica*. The results showed this method was steady and accurate such that it could be used to predict moisture content rapidly. Li et al.²³ have examined the moisture content in five extracts of CMM: *Scutellariae Radix*, *Lonicerae Flos*, *Forsythiae Fructus*, *Cornu Caprae Hircus* and *Bear Gall*. They demonstrated the general reliability and accuracy of the technique for the determination of moisture content in extracts of CMM²⁴. NIRS can also detect the moisture content of CMM rapidly. For example, Shi et al.²⁵ collected 6 batches of *Liuweidihuang* pills from different factories to establish a model for the spectrum and moisture content, which could provide a reference for quality. Similarly, Xiang and Wang²⁶ also utilized NIRS to build the moisture model of *Qijudihuang* Pills.

2.2.2. Detection of the main active components

It is the main active components that play a critical role in the CMM. Generally, high content of the active components is related to quality. Thus, the fast detection of the main active components is one of the most important parts in the quality control of CMM.

Huang et al.²⁷ have developed a method for the rapid determination of baicalin and total flavonoids in *Scutellariae Radix* by NIRS. It came out that the first derivative pretreatment and minimum-maximum normalization method can be applied to extract spectral information, and analyze the content of baicalin and total flavonoids, respectively. Zhou et al.²⁸ established a method for the detection of berberine in the *Cortex Phellodendri*. The results provided spectral information that can be extracted thoroughly by second derivative pretreatments method. Bai et al.²⁹ could efficiently test the content of *Patchouli* alcohol from *Cablin Potchouli* Herb based on NIRS.

NIRS has also been used to monitor the extraction process of CMM. Wu et al.^{30,31} used a rapid and non-destructive method to quantitatively predict the content of the three main active components in licorice (glycyrrhizin, liquiritin and isoliquiritin) by NIR. Meanwhile, model performance of the partial least squares method (PLS) and bagging-PLS was used to survey the pilot-scale extraction process in *Aurantii Fructus*, which could also constitute a suitable strategy for online monitoring of CMM. Li et al.³² investigated effective component dissolution by NIRS to monitor the total saponins in the extracting process of *Astragali Radix*, and Ni et al.³³ studied the relationship between NIR and HPLC during a water extraction process of *Salviae Miltiorrhizae Radix*. Comparing the two methods, they demonstrated that NIRS could provide analytical results that satisfied the precision

requirement of industrial production. Yang et al.³⁴ developed a new method for the process analysis of *Coptis chinensis* extracts. The model successfully predicted the elution curves of the alkaloids on macroreticular resin.

Powder blending is a key point in the production process. NIRS combined with chemometrics has also been applied in pharmaceutical blending. Liu et al.³⁵ introduced a new approach (Vector operation moving block standard deviation), to characterize the powder blend uniformity of *Angongnuihuang* pills immediately. Additionally, Ljiljana et al.³⁶ reported the usage of NIRS as a process analytical technology for monitoring the mixing process of metformin hydrochloride and vinylpyrrolidone. It could be concluded that the proposed technique will be an effective tool for the critical manufacturing step in the solid dosage form.

Apart from detecting the main active components, there are some other opportunities. Wu et al.⁵ took the *Yinhuang* oral solutions as an example to validate a hand-held AOTF-NIR method, paving the way for portable analytics. Wu et al.⁵ developed a method for *Lonicera japonica* which was proposed to estimate the multivariate detection limits of NIRS³⁷. Wu et al.^{38,39} also found the two systems were suitable as the process analytical technology to understand ethanol precipitation process of water extract of *L. japonica*. Lastly, Pan et al.⁴⁰ investigated an ensemble method as the means of monitoring the pilot-scale extraction process in *Aurantii Fructus*, which may also constitute a suitable strategy for monitoring of CMM.

Obviously, NIR belongs to the green analytical technique, which does not need to use reagents and cannot pollute the environment. Also, it will not destroy the samples during assay. Moreover, NIR has the advantage of simple operation and repeated measurement with a high accuracy. However, it is a new technique that warrants more attention to establish the calibration model necessary for NIR. Before the establishment of a calibration model, a large number of representative samples must be measured to acquire the necessary data. For this, it requires the financial support and professional people.

3. Chemical imaging

Chemical imaging (CI), which consists of imaging and traditional spectroscopy, generates many chemical indicators within a confined spatial area of the sample. The resulting photocurrent at each point of measurement will be mapped into a color representation and images of the electrochemical properties at the sensor surface can be generated⁴¹. Based on molecular spectroscopy, CI has been divided into ultraviolet chemical imaging, fluorescence chemical imaging, Raman chemical imaging, near-infrared chemical imaging, and middle infrared chemical imaging (Fig. 1)⁴².

Near-infrared chemical imaging sensors (NIR-CI), which combine conventional NIR with CI, have been put into widespread use (Fig. 2)⁴³. NIR-CI is a novel technique for the acquisition of qualitative and quantitative information about both the spatial and chemical characteristics of individual components at the micro-scale. It is well known that NIR-CI could provide spectral and spatial information simultaneously, and be utilized to visualize the spatial distribution of the ingredients in a sample⁴⁴.

Wu et al.^{45,46} have completed a series of studies on the application of NIR on CMM. They firstly provided the basis of the correlation between bioavailability and distribution of ingredients. A method to analyze hesperidin distribution and composition uniformity of *Rukuaixiao* Tablets was established. They

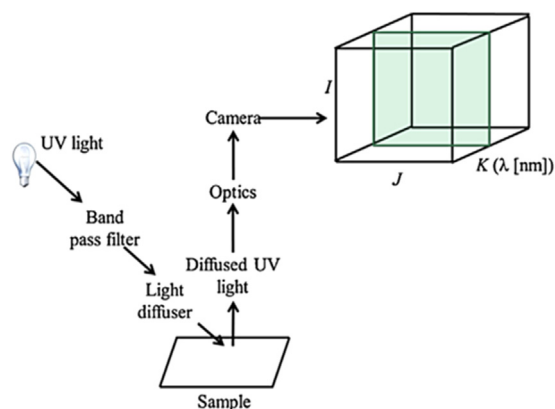


Figure 1 Graphical illustration of the measurement principle of the UV imager and arrangement of the obtained multi-wavelength data array. Reprinted with permission from Qiao et al.⁴².

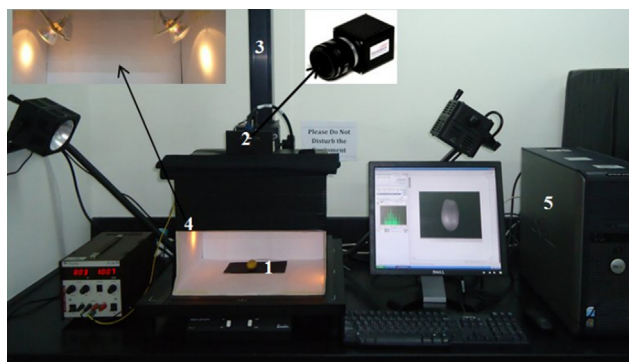


Figure 2 Experimental setup for an NIR imaging system. (1) Sample platform; (2) NIR camera; (3) Camera mounting stand; (4) Illumination; (5) Image acquisition system. Reprinted with permission from Qiao et al.⁴³.

created a novel application of NIR-CI for monitoring the blending process of Yinhuang powder, which highlighted a promising technology to extract critical process information and provided essential process knowledge of the blending process of Yinhuang powder. Similarly, Wang et al.⁴⁷ investigated the relationship between tablet hardness and homogeneity of different Yinhuang dispersible tablets by NIR-CI. Through it they provided a novel methodology for selecting the best hardness in the tablet process of Chinese medicine tablet. Moreover, Zhou et al.⁴⁸ focused on the pharmaceutical applications of NIR-CI in each unit during manufacturing processes from the western solid dosage forms to the CMM preparation. It could be concluded that the proposed technique could be an effective tool to monitor the critical manufacturing steps in the solid dosage forms. Additionally, Wu et al.⁴⁹ demonstrated the inter-tablet heterogeneity of both starch and total compounds distribution. The similarity of starch distribution and the inconsistency of total components distribution among intra-tablet were signified according to the value of slope and intercept parameters in the curve.

Above all, CI can visualize the state of process in pharmaceutical products, because CI not only provides image information of morphological content, but also presents the position or contents of the active components both static and dynamic in the CMM. Furthermore, compared with NIR, NIR-CI can obtain information on each component to achieve visualization. Because of the unique

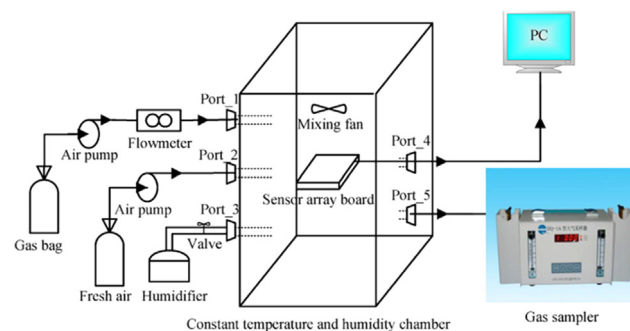


Figure 3 Systematic experimental platform in an electronic nose system. Reprinted with permission from Pei et al.⁵².

absorption spectrum of each material, there is no need to stain the samples to obtain colorful images, and samples require no reprocessing. For NIR-CI, how to ensure the stability and reliability of imaging data should be easily resolved.

4. Electronic nose

Electronic nose (EN), which imitates the perceptual mechanisms of biological olfactory using a chemical sensor array, is designed to detect and discriminate complex odors. Its advantages are fast detection speed, simple sample pretreatment and a wide range of sensitivities. Applications for electronic noses have been numerous, ranging from environmental monitoring⁵⁰ to medical applications⁵¹. In the term of CMM, EN also can distinguish smell to express a consolidated designation.

In order to visualize the EN system, the experimental platform was simplified and presented in Fig. 3. There are five ports (from port 1 to port 5), which are used in the chamber. For clarity, port 1 is used for injection of contaminants; port 2 is used to clean the chamber after each experiment through injection nitrogen; port 3 is set to control the relative humidity in the chamber by using a humidifier with a valve; port 4 is for data collection by connecting the PC to the sensor array board with a JTAG and port 5 is set to sampling by a gas sampler for true concentrations⁵².

4.1. Species identification

It is generally known that CMM possess many different botanical species and complex sources. In this case, the species identification is the first step to control medicine quality. According to the traditional quality evaluation system, smell is an important evaluation index, because most CMM release an odor that can be related to the species and authenticity. Therefore, we can extract the volatile odorant of CMM to make up a scent fingerprint.

Yang et al.⁵³ tested the odor differences among Rheum Palmatum samples of different species. It found the EN combined with principal component analysis (PCA) and discriminant factor analysis (DFA) could be applied to identify the different species of Rheum Palmatum. Furthermore, Tian et al.⁵⁴ established the detection methods of Chinese ginseng and American ginseng pieces by EN, to distinguish them by odor fingerprint figures. Zhang et al.⁵⁵ used EN to distinguish the fragrances of Chinese *Cymbidium* species and cultivars. Suchin et al.⁵⁶ developed a method for classifying garlic cultivars, because each garlic cultivar presented different response patterns. The results suggested that garlic cultivars could be classified simply and quickly by EN. Li

et al.⁵⁷ identified fast and accurately multiple sources of *Curcumae Radix*, providing a new approach for the identification of CMM. Taken together, these studies show that the establishment of the odor fingerprint by EN can make the identification of CMM more scientific and standardized.

4.2. Origins identification

CMM not only possess many different species, but also could be influenced by the characteristics of the environment. For instance, *Pulsatilla chinensis* can be grouped into 16 cultivars in China, and every cultivar is different in chemical composition, pharmacological effect and toxicity.

Specifically, the chemical components of CMM vary in the fields because of the different climatic and environmental conditions. The change of some volatile odorant will also lead to variation in the odor, which can be identified by EN. Wang et al.⁵⁸ developed an effective method to distinguish the producing areas and grade of *Aconiti Lateralis Praeparata Radix* (Heishunpian). In the study, 20 batches of Heishunpian samples could be clearly distinguished. Moreover, Peng et al.⁵⁹ appraised rationally the quality between wild and cultivated *Atractylodis Macrocephalae Rhizoma*. The results found that the odor of wild *Atractylodis Macrocephalae Rhizoma* differed from that of the cultivated forms. In some instances, EN combined with PCA and DFA could be applied to identify CMM. For example, Han et al.⁶⁰ detected the odor difference among *Chrysanthemi Flos* samples of different regions and found the samples could be clearly separated by PCA and DFA. Also, Shao et al.⁶¹ tested *Atractylodis Rhizoma* from three producing areas and analyzed them by linear discriminant analysis (LDA). The correct recognition rate was up to 97.8%. Wu et al.⁶² utilized EN to discriminate the CMM with different growing areas and harvesting dates in the natural state. The accuracy of identification in unknown samples was up to 100%.

Furthermore, Liu et al.⁶³ developed an EN coupled with multivariate statistical analyzers to rapidly and nondestructively recognize *Angelica sinensis* from the authentic regions and unauthentic regions. Huang et al.⁶⁴ identified the botanical origins of honey as well as determined its main quality components, such as glucose, fructose, hydroxyl methyl furfural, amylase activity, and acidity. The overall results showed that the laborious, time-consuming, and destructive analytical methods like HPLC, acid-base titration, and spectrophotometry could be all replaced by EN. To compare and evaluate the quality of similarity of *Ligusticum chuanxiong Hort.* produced in different regions, Chen et al.⁶⁵ analyzed the volatile components and concluded that the whole nature of volatile components was similar, but it was significantly different from Xionglingsi of the substandard level. Additionally, Yang et al.⁶⁶ compared the smell of wild *Angelica sinensis* and cultivated *A. sinensis* by EN.

4.3. Detection in concocted processing

Through the concocted processing, one can correct odor, reduce adverse effects and improve curative effect. For example, the content of diester alkaloids in *Aconiti Kusnezoffii Radix* is reduced and hydrolyzed to aconine after processing. Apparently, the odor will change with the processing. Therefore, we can judge the quality of CMM depending on the changing odor.

However, it is difficult to monitor the changing odor owing to many uncertain factors. Huang et al.⁶⁷ undertook an investigation

on discriminating processed betel nut's degree of stir-frying and quantized empirical index. They set up a standard of duration and degree of heating based on the odor's characteristic. Yin et al.⁶⁸ used EN to detect the odors of *L. japonica* samples during a storage period of 16 months. The content of chlorogenic acid of *L. japonica* was determined to confirm the quality changes and investigate its correlation with odor response values. Shao et al.⁶⁹ revealed regular patterns of variation in odor between unprocessed and processed *Herba Siegesbeckia*. The results indicated that the odor of unprocessed and processed samples had a significant difference, and this variation could be digitalized according to odor characteristic parameters tested with EN.

With the comparison of traditional analytical instruments, EN has a more powerful ability to obtain a wider spectrum of information on gas samples. The measurement speed is fast which can provide timely feedback to adjust the process conditions, ensuring production quality. However, the sensors in the EN are easily affected by environmental factors, such as humidity, temperature and vibration. Besides, they may overload or fail occasionally. At present the application of EN still remains in the laboratory stage.

5. Electronic tongue

The electronic tongue (ET), known as a promising tool for taste assessment, can mimic the human taste sensors, making itself an analytical instrument that artificially and effectively reproduces the taste sensation. Now, ET has the ability of testing the basic taste sense: sourness, sweetness, bitterness, umami and saltiness so that it can recognize the qualitative and quantitative composition of multispecies solutions. However, unlike other analytical methods, ET only presents a digital fingerprint, without acquiring data on the nature of the compounds. The distorted information due to overlapping or interfering signals can be modified by chemometric tools⁷⁰.

Basically, ET attempts to represent and imitate what is happening when molecules with specific taste properties interact with taste buds. The taste buds are represented by sensors which interact with these molecules at the surface initiating changes in electric potentials (Fig. 4). These signals, which can be compared to physiological action potentials, are recorded by a computer system. The obtained data can be evaluated afterwards on the basis of an already existing matrix of sensor responses which is comparable with association to already known taste patterns⁷¹. In perspective, ET can be one of the clearest benefits of the application in sensor research. One of the clearest fields of application for ET is in the food field, where the automated sensory control of fabrication batches and detection of production defects can be an invaluable contribution. Meanwhile, distinguishing the characteristics of CMM with the ET will also become an important direction of the identification in the future⁷².

5.1. Distinguishing drug taste

It is hard to objectify the taste sense, but the ET has the ability to evaluate taste objectively, which can realize the specific effects of CMM. Therefore, some researchers have investigated the potential of ET in CMM.

Zheng and Keeney⁷³ took the first steps in evaluating the feasibility to differentiate bitter tasting drugs and to rank them according to the degree of bitterness. Caffeine anhydrous,

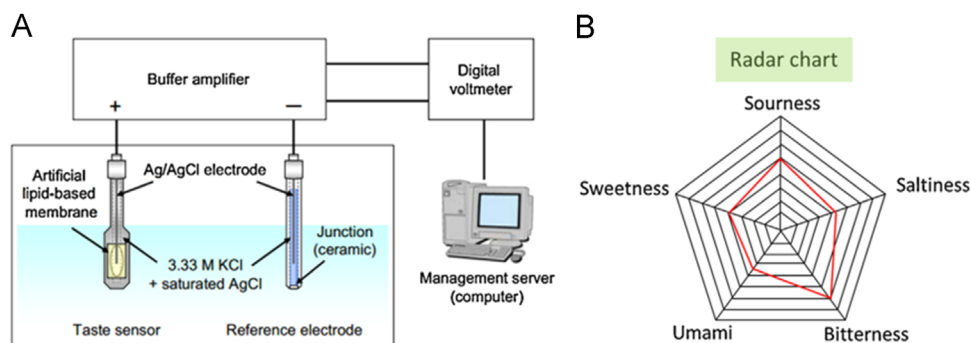


Figure 4 (A) The diagram of taste-sensing system. (B) Radar chart as pattern recognition of foodstuff with different taste properties. Reprinted with permission from D'Amico et al.⁷¹.

paracetamol, phenylthiourea, prednisolone sodium, quinine hydrochloride, ranitidine hydrochloride, and sucrose octa-acetate were investigated at the same concentration and a bitterness ranking was determined. Ammar et al.⁷⁴ presented an improved classification of *Orthosiphon stamineus* using a data fusion technique. Five different commercial sources along with freshly prepared samples were discriminated using both EN and ET. In addition, Japanese researchers studied the evaluation on Chinese prescription. Li et al.⁷⁵ used ET to identify the change of taste in a stir-fried process of *Crataegi Fructus*. According to the results, the processed degree of raw samples could be classified into three types, including stir-fried, scorch-fried and charred *Crataegi Fructus*. ET can employ taste as the new parameter to objectively describe the processing and improve the processing quality accurately.

5.2. Detection of undesirable drug taste

Many CMM have an undesirable taste, especially bitterness, which results in limiting the usage of CMM in clinical applications. To improve the taste, bitterness suppressants are added. Thus, evaluation of undesirable drug taste by ET has become main direction in the recent research.

ET is useful in detecting the bitterness and evaluating the effect on modification the undesirable taste. Harada et al.⁷⁶ established an acceptable prediction of the bitterness intensity of propiverine hydrochloride based on a model consisting of five other bitter tasting drugs. At the same time, Li et al.⁷⁷ utilized berberine hydrochloride as model drug of bitterness, sodium cyclamate, 2,4-dihydroxybenzoic acid and sodium cyclamate as bitterness inhibitors. The result of this experiment was the same as found with human taste results. Rachid et al.⁷⁸ investigated the evaluation of sweetening and flavoring agents on the bitter taste of epinephrine, and even set up a model to predict bitterness.

5.3. Evaluation of the quality of CMM

The ET not only can determine the concentration of an extract of CMM, but also enables one to compare the quality of principal components in different solvents extraction.

Kataoka et al.⁷⁹ studied the quality control of 11 medicinal plants and 10 kinds of CMM. Groups of secoiridoid glucosides, triterpene derivatives, and alkaloids of the berberine type could be identified by ET. Further, two medical plants as well as the same plants coming from different locations were compared with each other. A good correlation between EN measurements and HPLC detection of berberine amount was found. Wu et al.⁸⁰ also tested

the ability of ET on the quality of CMM from different species, place origins and production batches. For another, Liang et al.⁸¹ isolated alkaloids from *Coptis chinensis* Franch. The components were identified as berberine, columbamine, groenlandieine, jatrorrhizine, magnoflorine, corydaldine and ferulic acid methylester. The researchers measured their bitterness based on the ET and evaluated the antibacterial effectiveness. They demonstrated that there was a close relationship between the bitter degree and antibacterial activity of bitter components. Thus, it has been confirmed further that bitter components were the material foundation of medicinal effectiveness⁸¹. Moreover, Carolin et al.⁸² elaborated the application of ET as an alternative method in quality control of herbal lozenges. In comparison to human taste assessment, ET was more capable of distinguishing between specified and outlying taste. Data evaluation based on univariate statistics as well as multivariate could be utilized to detect the different samples. Therefore, the insentient taste sensing system appears to be a promising analytical tool for quality control of complex herbal mixtures.

It is well recognized that ET can mimic the human taste sensors and reproduce the taste sensation effectively. Moreover, the application of ET avoids complex pretreatments, such as HPLC and GC, as well as eliminates individual variation in taste by different operators. Therefore, the data can provide good repeatability and high sensitivity. Importantly, ET showed its unique advantages in determination of CMM toxicity or irritant agent. But similar to EN, ET also seems difficult to incorporate into industrial use. Although the data can be collected effectively, these systems still require a strictly suitable post-processing procedure of analysis and classification.

6. Conclusions

In this paper, we have outlined the major contributions of NIR, CI, EN and ET relevant to most published fields within CMM. Obviously, quality evaluation of CMM is crucial to ensure its safety and effectiveness, leading to an important role in research and commercial applications. However, due to the complex chemical composition and the interaction of different components, it is difficult to assure the safety and effectiveness of CMM. Nonetheless, the new sensor systems seem to possess more advantages than traditional techniques. Therefore, new sensors have been applied to investigate CMM and provided a useful platform for fast, simple and clear gathering of taste information. Compared with EN and ET, NIR and CI possess relatively integral systems to detect CMM. EN and ET exhibit good correlation with

the human sensation and can effectively mimic it. Through combination with different chemometric processing, they have showed intelligent capability for recognizing the qualitative and quantitative compositions of multispecies solutions.

Although the achievements presented in this review seem to be very promising, there still exist many difficulties. On the one hand, once the data is collected, these systems should require a suitable post-processing procedure to analyze and classify the data. Preprocessing of multivariate signals in sensor arrays represents an essential part of the measuring system. To find the way of getting the qualified data and deciphering it is of the same importance. Moreover, the object detection is limited to some extent. For instance, because of the rather low content, the toxicity of some CMM is difficult to detect. Apart from this, the new sensors are advanced technologies, which means we have to make much effort in it, including more time and investment. Therefore, while the new sensors present a number of advantages over traditional technologies, there are many shortcomings which have yet to be solved.

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