Bibliometric analysis and survey on electronic nose used in agriculture

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ABSTRACT

Work carried out at the beginning of this century on improvements in semiconductor materials, transducers, sensors and artificial intelligence algorithms led to the rapid expansion of research topics related to the electronic nose, with diverse applications. Agriculture is a recent application field that needs a review of the usage of electronic noses in this field and the future challenges. The paper provided a bibliometric analysis and review of electronic noses used in agriculture. A search of published works on the e-nose and its applications in agriculture was carried out in the Web of Science and Scopus databases, which provide comprehensive citation data for academic disciplines worldwide. In the end, 2,953 documents were identified, and the data collected was analyzed mainly using the bibliometric toolbox, and then a deep study was carried out. The study results show that in the agricultural field, some works were achieved on different varieties of plants to detect disease or plant damage with very good results using electronic noses. However, less research was carried out to directly identify animals in crops like pests or environmental monitoring using electronic noses in agriculture. Some recommendations for future research efforts are finally provided.

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1. INTRODUCTION

The animal's olfactory system performs many functions, like detecting odors, food and danger [1]. Artificial olfaction, or the electronic nose (e-nose), with its ability to simulate the human nose, plays an essential role in robotics, and can therefore be used to detect and differentiate odors accurately and cheaply [2]. This potential means they can be used in a wide range of applications: the food industry, the pharmaceutical industry, medical diagnostics and environmental monitoring. The electronic nose may therefore have the potential to achieve many applications in agriculture. However, in order to make a significant contribution to this field of application, a good overview of the use of the e-nose in agriculture is required. Bibliometric methods make it possible, firstly, to highlight and quantify collaboration not only between institutions and journals, but also between publications, their authors and their countries. Secondly, they enable us to identify current trends on particular themes. Bibliometric analysis also makes it possible to assess technological advances and difficulties encountered in the research topic under study, even geographically. Last but not least, bibliometric methods help to make informed choices about research topics, and hence about the funding of scientific research [3]. A bibliographic analysis of the electronic nose and its application in agriculture was conducted, and a short literature study was also made. This paper addresses the following research questions: i) Who are the most cited authors and who have contributed the most to scientific production in the field of electronic noses? ii) Which journals and countries have the most relevant work in the field of electronic noses? iii) What is the current research on electronic noses used in agriculture? and iv) What are the most promising research directions for using electronic noses in agriculture?

The article carries out a quantitative study of publications on electronic nose. The collection of publications studied comes from the Scopus and Web of Science databases. The work thus addresses these research questions. The paper is organized as follows: section 2 presents our research methodology. Section 3 presents the results and discussion. Section 4 presents the conclusion.

2. METHOD

To carry out this research, we developed a search method aimed at selecting relevant documents in literature. Many bibliographic data are available in various databases, such as Scopus or Web of Science (WoS). Some articles are listed in both databases. In addition, other highly accessible sources are often very voluminous, such as Google Scholar, or highly specialized, such as IEEE Xplore, ACM Digital Library, for example. For the purposes of this study, therefore, we will be using Scopus and WoS, which, thanks to their in-depth search functions, enable us to select sets of relevant articles, which then form the basis of our bibliometric analysis. The articles obtained from the Scopus and WoS databases have been studied independently to see if the patterns of scientific contribution are the same in both databases. The search keywords used were the following: "electronic nose" or "e nose".

In the Scopus database, searches were carried out from the database's inception to 2022, and included research reports, journal articles, conference proceedings and review papers, all published in English. The search mainly focused on mapping existing literature on electronic noses in all fields, such as medicine, environmental science, chemistry, gastronomy, and agriculture. The research span was from 1999 to 2022. All documents prior to 1999 have been withdrawn from the collection. At this stage, we have collected around 2.5 thousand research articles. The preliminary analysis of the time span of this article database shows that 80% of works were made in the last ten years, that is, between 2012 and 2021. Thus, the search was restricted to these 1,956 articles. Then, we made a deep analysis of this article database to identify, firstly, the most relevant articles and authors, and secondly, the journals that published more works on that topic. The search then narrowed the subject area to an agricultural field. So, 85 articles were extracted at this level.

On the WoS database, we collected 997 papers spanning between 1996 and 2022. This collection also includes research reports, journal articles, conference proceedings and review papers, all published in English. The same analysis made on the Scopus collection was realized to firstly appreciate the most relevant articles and authors and, secondly, the journals that published more works on that topic. The search then narrowed the subject area to an agricultural field. 372 articles relate to the use of the electronic nose in agriculture. Those articles were extracted at this stage. In addition, to maintain the quality of the review, article abstracts were thoroughly examined for analysis and purification from the article collection to ensure the relevance and quality of the papers selected for the study.

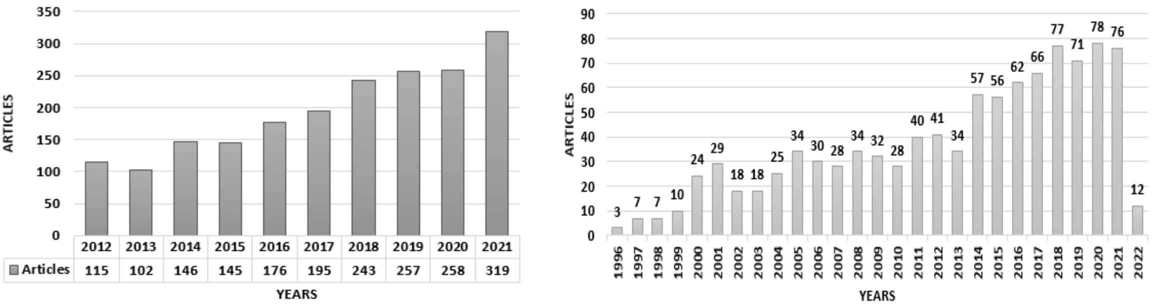
3. RESULTS AND DISCUSSION

In this section, we explain the results of our research. At the same time, we gave a comprehensive discussion of the results. The first sub-section discusses the general uses of e-nose, and the second sub-section discusses its use in the field of agriculture in particular.

3.1. Bibliometric analysis: a global overview on electronic nose

The first analysis of the set of articles focuses on the distribution of the publications during the working timespans. Figure 1 shows the number of publications per year on the topic of e-nose. This presentation is made for each dataset collected on Figure 1(a) for Scopus and Figure 1(b) for Web of Science. Since 2012 and 2013, the total number of publications in Scopus has been steadily increasing, as far as we can tell, and this trend appears to be continuing today. And in particular, we note that the number of works published per year on electronic noses over the past four years (2018–2021) is noticeably higher than the average publication over the past ten years, which was 196 articles. This is something that we have observed.

Only in the past year, 319 works on e-nose-related topics were published, which is more than sixty percent higher than the publication average of the previous ten years. This enables us to confirm the growing interest in this technology and to forecast an increase in the number of publications pertaining to e-nose in the years to come.



(a) (b)

Figure 1. Distribution of e-nose topic publications for (a) Scopus dataset and (b) WoS dataset

We observe a sawtooth pattern in the progression of scientific production over the past quarter of a century using the WoS dataset. During this time period, beginning in 2014, there has been a significant increase of almost fifty percent in the output of scientific research, which has continued to gradually increase up until the present day. The number of publications that has averaged out to be 75.5 articles per year over the course of the previous four years is higher than the number of publications that has ever averaged out to be in any previous year. As a result, we are able to reach the same conclusion as we did with the Scopus data, which is that research on electronic noses is presently undergoing a significant resurgence of interest. It is not difficult to imagine that the rate of expansion of electronic nose publications will come to a halt in the year 2020. It is likely to be brought on by the widespread COVID-19 pandemic. Despite this, we anticipated an increase in the amount of work involving e-nose in the years to come.

The articles that are included in our datasets come from a variety of different sources. The number of publications that come from each of the top 20 sources that are relevant is shown in Figure 2. The results for Scopus are displayed in Figure 2(a), and the results for Web of Science are displayed in Figure 2(b).

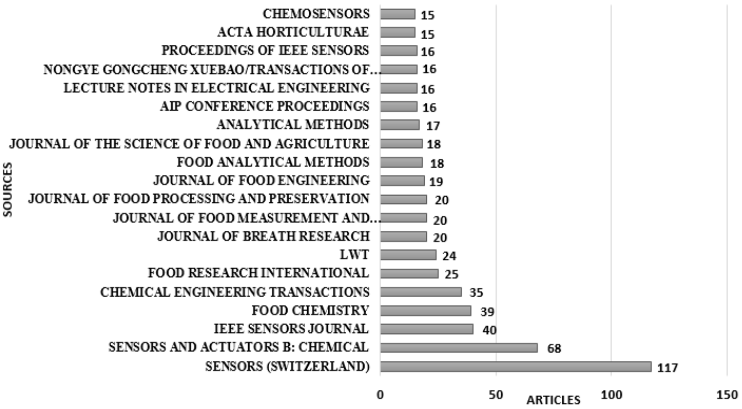
Figure 2(a) shows us the Sensors (Switzerland) journal, like the best relevant sources, which publish more articles on electronic nose topics in Scopus. Then, 117 articles come from this review, and it is about twice as many (1.72) articles as the second source (Sensors and Actuators B: Chemical), who published 68 articles over the same period. Again, based on a deep analysis of only 4 years, we remark that these two journals published 92 articles on the single electronic nose topic. This production significantly contributes to the growth of annual production in this field.

In Figure 2(b), the sources that publish the most on e-noses are shown. These sources are indexed in the Web of Science database. The journal Sensors and Actuators B: Chemical has 103 articles, making it the most productive source. Sensors (Switzerland), which has 61 articles, is ranked as the second most productive source. Based on these results, we can conclude that these two sources are, in all honesty, the most productive when it comes to the subject of electronic noses. Differences in the quantity of information amassed by Scopus and Web of Science can be deduced as the cause of the observed shifts in ranking positions.

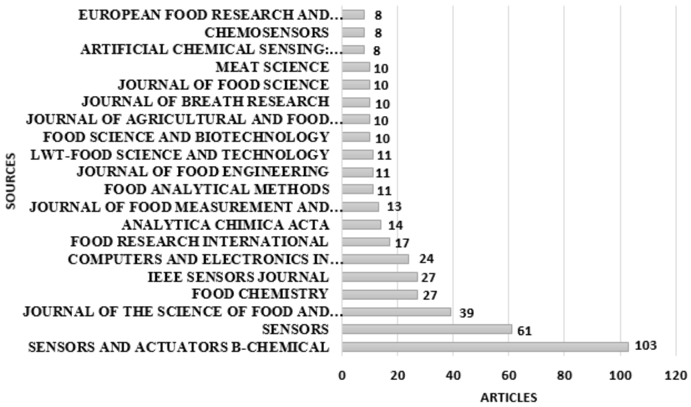
Furthermore, out of the top 20 most relevant sources discovered across both databases, only 12 were cited by both of those databases. Because of this, we are able to determine which 28 sources are the most relevant by looking at which two databases (Scopus and WoS) and seeing which sources have the highest rankings. Many authors have put in a lot of effort over the course of the past few years to advance our knowledge of e-nose. The fifteen most prolific authors in relation to this subject are listed in Table 1. According to Table 1, Wang J holds the top spot on this list with a total of 85 publications and 32 of those publications are related to two different databases. In spite of the significant gap in the amount of information amassed by the two databases, there are five authors who are present on the list of the fifteen most important authors. The names of these individuals are Wang J, Wang Y, Liu Y, Tian F, and Wang Z. These remarks are supported by Figure 3, which presents the scientific production of various countries in relation to the e-nose topic using two different databases.

The diagram in Figure 3(a) shows that of the fifteen countries that work the most on the electronic nose, China alone has 47% of scientific production on the electronic nose. As a result, Chinese works (cited 8,939 times) are therefore the most cited in the world, ahead of Italian (cited 2,177 times) and the United

States (cited 1,180 times). In the same vein, the diagram in Figure 3(b) shows that China is the first country to write more on the subject of the electronic nose. This contribution amounts to 37%, with Chinese works being the most cited (4,215 times), followed by Italy (2,878 times) and the United States (2,482 times). These are the three most cited countries in the world, from three different continents, and are therefore representative of the global dynamics of e-nose research. However, the African contribution remains minor, with Morocco (2%) being the only African country on the list of the fifteen most productive countries (in the WoS database). On the basis of the dataset, many keywords can be collected. Figure 4 is a picture that is characteristic of the different uses of keywords around electronic nose work.



(a)

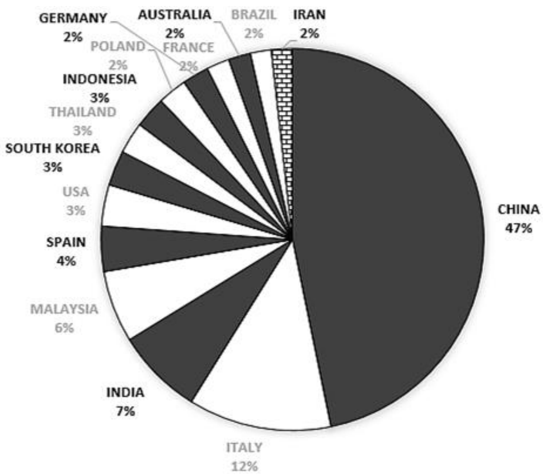


(b)

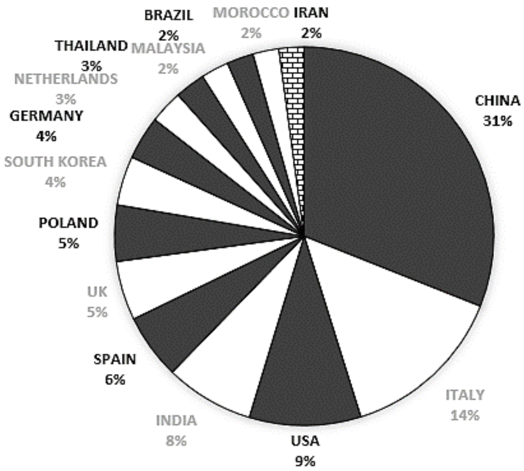
Figure 2. First twenty relevant sources of e-nose topic publications for (a) Scopus dataset and (b) WoS dataset

Table 1. The fifteen more relevant authors in e-nose topic for Scopus and WoS

Scopus database		WoS database	
Authors	Articles	Authors	Articles
Wang J	85	Wang J	32
Wang Y	53	Bhattacharyya N	20
Tian F	43	Wang Y	17
Kerdcharoen T	39	Llobet E	15
Liu Y	37	Bouchikhi B	14
Zhang L	37	Tudu B	14
Zhang D	34	El Bari N	13
Zhang M	32	Bandyopadhyay R	12
Liu H	27	Liu Y	12
Li J	26	Namiesnik J	12
Yu H	26	Tian F	12
Jia P	25	Yang Y	12
Wang L	25	Bermak A	11
Li X	24	Di Natale C	11
Wang Z	24	Wang Z	11



(a)



(b)

Figure 3. Country scientific production for (a) Scopus dataset and (b) WoS dataset

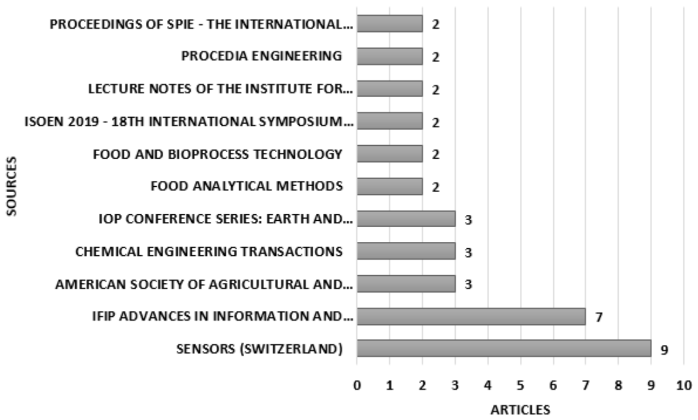
Figure 4. Most used keywords in e-nose works

An in-depth examination of this distribution reveals that the primary method employed in electronic noses for odor recognition is principal component analysis. It is used to identify the volatile organic compounds present in a sample's odor. However, the progress in artificial intelligence methods enables a greater emphasis on alternative approaches to identifying odors, such as support vector machines and neural networks. Following a comprehensive examination of electronic nose research worldwide, our focus shifted to the specific studies that explored the applications of electronic nose technology applied to the agricultural field.

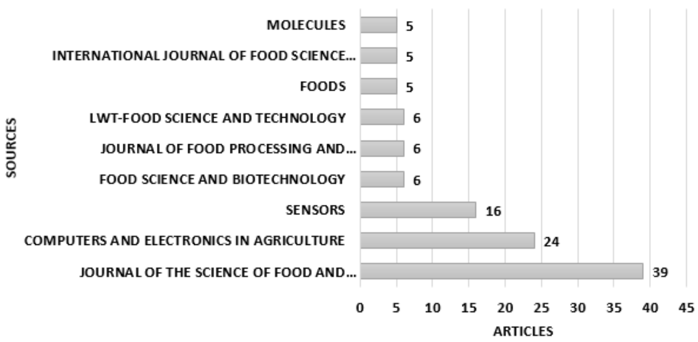
3.2. Electronic nose in agriculture field

Of the 1956 electronic nose articles collected in the last ten years, only 85 have a special application in the agriculture field. The use of electronic noses to solve problems in agriculture has increased in recent years. This is justified by the number of articles published per year during the last five years, which is higher than the average (8.5) publication over the ten years studied. Then, of the 997 articles in the WoS database, 372 address an application in agriculture, and only 289 have been published in the last 10 years. The average scientific production in the last 5 years has been 42.2 articles per year.

A large number of papers in WoS (289/997) deal with the use of e-nose in agriculture compared to Scopus (85/1,956). This may lead to the conclusion that WoS indexes many more agricultural journals than Scopus. The high use of e-noses in agriculture indicates that they can certainly help to improve intelligent agriculture. Figure 5 summarizes the most productive journals on the use of e-noses in agriculture. The results for Scopus are shown in Figure 5(a) and for Web of Science in Figure 5(b).



(a)



(b)

Figure 5. Most relevant sources of e-nose used publications in agriculture for (a) Scopus dataset and (b) WoS dataset

The Scopus and WoS-indexed review "Sensors (Switzerland)" appear to publish a lot of work on electronic noses as well as a specific use in the field of agriculture. Only agricultural journals such as "Journal of The Science of Food and Agriculture" and "Computers and Electronics in Agriculture" are ahead in the WoS database. This confirms the remark that WoS indexes more journals specializing in agriculture than Scopus. Although little work is being done around the world on the use of the electronic nose in agriculture, some authors have distinguished themselves with multiple productions in this field. Table 2 presents the ten most prolific authors.

According to the general trend of scientific production on e-nose technology, which puts China first, it can be seen from Table 2 that the Chinese have done much work on e-nose technology used in agriculture. The most prolific author (Wang J) on e-nose technology is included in the list of the ten authors who have done very more work on their application in agriculture from Scopus. He is always the most prolific author in the agricultural field from Web of Science.

Looking closely at the keyword map in Figure 6, we identify the relevant topics highlighted in Figure 4. Thus, volatile organic compounds (VOCs) and principal component analysis (PCA) are indispensable elements in the use of electronic noses in agriculture. We can confirm that this PCA technique this PCA technique is more relevant in e-nose technology. But this suggests that many other methods should be used to explore another possibility to solve pattern recognition problems in e-nose technology. Many of the most cited works are discussed in detail in the following section.

Table 2. The ten more relevant author in e-nose used publications in agriculture from Scopus and WoS

Scopus database		WoS database	
Authors	Articles	Authors	Articles
Dymerski T	6	Wang J	20
Kerdcharoen T	6	Zhang M	14
Pobkrut T	6	Wang Y	12
Namieśnik J	4	Wang L	8
Wang J	4	Bhandari B	6
Kuchmenko TA	3	Hu Q	6
Umarkhanov RU	3	Li J	6
Wardencki W	3	Li X	6
Abdullah AH	2	Panigrahi S	6
Adom AH	2	Yu Z	6

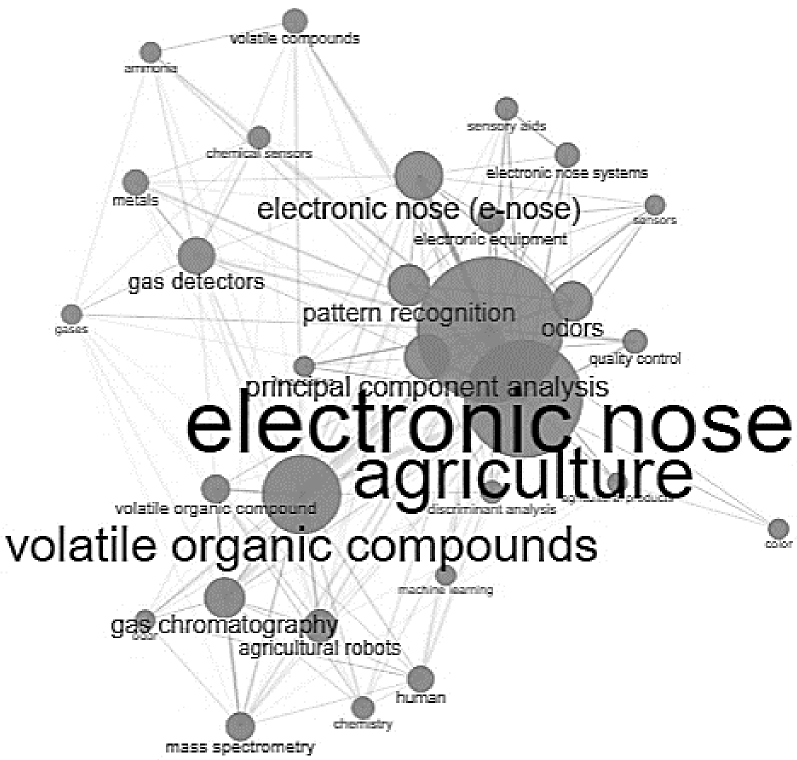


Figure 6. Most keywords used in e-nose works in agriculture

3.3. Synthesis works

Synthesis work has been carried out on the different applications and technologies of the electronic nose [4]–[9]. Some of them [10]–[13] show that electronic nose technology is increasingly being used in the agriculture field. It is also used in more specific applications on different axes, such as agronomy, the detection of pesticides, infestation detection botany, biochemical processes, plant physiology, soil pollution, and monitoring of the agricultural environment [14]. E-nose can more specifically sense the specific volatile organic compounds produced by fruits, vegetables, soil, flowers, plants, inputs, or air. As presented previously in the bibliometric study, several studies have been carried out on the use of electronic noses in agriculture. Some works are therefore presented here to identify the current use of electronic noses and the most used data analysis techniques.

3.3.1. Plants-oriented applications

A related study was performed in [7] to detect and monitor the flavor of tomatoes. Their research was to determine the impact of different postharvest handlings, including blanching treatment (BT) and chilling storage (CS), on the flavor of tomatoes. They also tested the possibility of using a commercial electronic nose for the prediction of physical and chemical parameters of tomatoes during the different post-harvest processing stages. To achieve their objective, sample preparation and post-harvest handling of tomatoes were divided into three batches, namely CS, BT and control. Physicochemical parameters such as total soluble solids (TSS) as well as total acids (TA) or TSS/TA were measured. Experimental results showed that the electronic nose is capable of detecting (together with LDA) variations in the handling of tomatoes in a post-harvest processing process and indicated notable odor changes for chilling storage and blanching. processed tomatoes. The electronic nose was also found to be an accessible way to predict (with K-nearest neighbors (KNN)) the total soluble solids (TSS) content and firmness of tomatoes during post-harvest treatments. The authors also point out that, based on physicochemical parameters, LDA could not sort out the different post-harvest treatments of tomatoes, with the exception of tomatoes treated at 100 °C BT, which has a significant impact on taste and mouthfeel. Similar works were carried out in [15], [16] and a result concluded the good classification of tomato and mint.

In study [17], the aim was to assess the use of the electronic nose carried out around ultra-fast gas chromatography to easily discriminate agricultural substrates by their origin. For their experiments, nineteen samples, namely maize, wheat and rye substrates, were processed. For data analysis, methods such as principal component analysis (PCA), clustering algorithm using flexible independent modeling of class analogies (SIMCA), discriminant function analysis (DFA) and statistical quality control (SQC) were used. Contrary to the work results described in [18], PCA and SQC have some bad results. Only the analyses carried out with SIMCA and DFA made it possible to discriminate between agricultural substrates on the basis of their agricultural origin. These results could be used for quality authentication and certification in the foods industries.

Abdullah *et al.* [19] focuses on the difficulties of creating a wearable electronic nose made from carefully selected sensors and an integrated controller with optimal capabilities. The authors use metal oxide semiconductor (MOS) sensors and multi-criteria statistical analysis methods such as hierarchical cluster analysis (HCA), principal component analysis (PCA) and linear discriminant analysis (LDA) to classify odors. They operate with fifteen sensors reduced to ten thanks to the PCA. The LDA method allows Ganoderma boninense to be discriminated from natural air. The percentage of correct classification in the experiment was 100%.

Dymerski et *al.* [20] used an electronic nose to perform a rapid assessment of agricultural substrates of different qualities. The measurements were achieved using a prototyped electronic nose made up of six semiconductor sensors. Three data processing methods were employed: single-link cluster analysis, principal component analysis and cluster analysis with the sphere method. The results proved a limited ability to differentiate different grades of agricultural substrate classes due to the low detection capacity of semiconductor sensors, high volatility and low concentration of volatile organic compounds in agricultural substrates. Thus, recognition with the three data analysis techniques was successful only for very good quality substrates.

Adam *et al.* [21] aimed to use an electronic nose to monitor completely stirred tank reactor stability from a pilot-scale to a full-scale agricultural co-digestion biogas plant. The authors used the multivariate statistical process control techniques (MSPC) approach to compare data from online electronic noses (using MOS sensors) exposed to the headspace pilot-scale reactor and then upscaled to a full-scale agricultural reactor. The e-nose indicator was useful in distinguishing three different process states: steady-state, transient, and collapsing processes. It also issued a warning when a major disturbance occurred in the two reactors under study. However, an important missing process variable in this work was the rate of gas and methane production in order to clearly distinguish steady-state processes from unstable processes and finally appreciate reactor performance.

Designing a rapid, non-invasive, real-time detection tool for rice quality monitoring was the main objective of Xu *et al.* [22]. To achieve this, the volatile organic compounds that characterize the odor profiles of rice were presented, and an electronic nose measuring device was used to assess the quality of rice by analyzing the variation in aromatic signatures. VOCs such as aldehydes, 2-acetyl-1-pyrroline (2-AP), alcohols, and heterocycles have been found to be the main contributors in rice aging, and the electronic nose has also reached the same conclusion. According to the authors who have done the same work [22]–[24] electronic noses can be used as non-destructive, real-time tools for monitoring rice quality and age by odor. Even if more efficient detection algorithms are explored.

In Wen *et al.* [25] made their own sweeping electronic nose system to find citrus fruits that had been infected with Bactrocera dorsalis early on. Eight metal oxide semi-conductors' sensors and PCA and LDA analysis methods were used. So, the samples from the batches infested with pests and control batches were analyzed and discriminated against. In addition, the citrus infestation period was well identified by the LDA model during the processing phase, with an accuracy rate of 98.21%. The related studies [26]–[29] were achieved to evaluate data collected by the electronic nose for the differentiation of tea leaves with different defects. The classification results with the subtle joint use of SVM and locality preserving projection (LPP) were successful with 100% accuracy.

The aim of Rizzolo *et al*. [30] was to analyze if a commercial portable electronic nose (PEN3) would be able to early identify palm pests, Rhynchophorus ferrugineus Olivier (RFO) by observing the immediate environment of the crowns and leaves of healthy, drilled and attacked palm trees. The PCA and LDA methods, regardless of the number of RFO larvae, have discrimination performance of 76.7% for air samples and 100% for leaf samples. According to the authors, their preliminary work concluded that the electronic nose could be an effective tool for monitoring RFO pests. Those works [31]–[33] conclude that the coupled use of the electronic nose and the good analysis method, especially the SVM method, could make it possible to identify diseases and pests on plants.

The purpose of Kishimoto and Kashiwagi [34] was to check whether fruit oil attacked by olive mealybugs presented particular odor profiles. Thus, a commercial Heracles II electronic nose was used to analyze the odors of oils from infested and healthy fruits. The result indicates that the rapid variations corresponded specifically to volatile organic compounds in the bad odor of the infested fruit oil.

3.3.2. Animals-oriented applications

A recent study [35] proposed a design of a hand-held electronic nose for food analysis. Who experiments were carried out to see if the electronic nose prototyped with commercial MOS sensors could be used in a real environment for the study of animal (fish, pork and poultry) and vegetable (olive oil) products. So, they used PCA and support vector machine (SVM) method to sort poultry meat batches. This classification was done with 100% accuracy based on shelf life and with 100% accuracy batches of rapeseed oil based on the degree of thermal degradation. This same prototype was also used for the identification of olive oils adulterated with rapeseed oil with an accuracy of 82%. Their prototype, with its design in several modules, offers numerous prospects for several applications.

A deep study has been carried out in [36], to determine the meat quality using nondestructive methods for determining its composition and quality. Many methods were explored. Only color and computer image analysis, visual near-infrared (NIR) spectroscopy, nuclear magnetic resonance imaging (NMRI), electronic nose, ultrasound, x-ray imaging, and Biosensors are non-intrusive quality assessment methods that have demonstrated real potential for meat analysis. But the study of colors and images is much more effective given the hygiene of the meat, the different conditions, tenderness and the effects of treatments and storage duration. The accuracy would be between 72 and 95%.

The study [37] wanted to find out where honey comes from botanically and what its main quality components are, like glucose, fructose, hydroxymethylfurfural (HMF), and amylase activity (AA). To achieve their goal, the authors used an e-nose based on eighteen metal oxide sensors. Principal component analysis (PCA), partial least squares regression (PLSR), and discriminant factor analysis (DFA) were employed to discriminate honey samples from 14 botanical origins. Least squares support vector machines (LS-SVM) were used and established 100% overall accuracy for the discrimination of honey origin.

The study [38] looked at how electronic nose tools could be used to find postpartum endometritis in cows early on by analyzing their secretions. To reach their aim, they use as samples four clinically healthy cows and four cows with endometritis. They checked a different cow's secretions on a different day with eight sensors based on piezoelectric crystals, like the electronic nose (developed by the MIP LLC "*Sensorika-Novye tekhnologii*"). The graphical analysis was carried out while appreciating the result. Cows with postpartum metritis were detected by their changing odor characteristics on sampling from day six today eight.

The goal of this work was to design a control system for livestock waste odor in order to monitor pollutant odors [39]. So, the authors designed and realized a control system that employs metal oxide semiconductor gas sensors and an air pump using fuzzy logic methods implemented on the Arduino Due microcontroller. The experimental results show that the system reduces the odor pollutant, like ammonia, from 9.93 ppm to 1.18 ppm in 4.5 minutes.

The study [40] was made to detect Ephestia kuehniella pest densities in white flour. For this purpose, six MOS sensors assembled as electronic noses with PCA/LDA multivariate statistical models were built for pest density detection. Relevant performances were achieved with LDA, which provided the highest prediction abilities on the fifth instar with an accuracy of 90%. Like the authors of this work, others [41] also concluded the use of the electronic nose as a noninvasive early disease diagnosis on plants.

In work [42]–[44], those researchers aimed to control pests, especially fall armyworm pests, in crops. They proposed a new approach: a multi-level monitoring mechanism-based electronic nose using smart MOS sensors. In this way, they compared this method with other methods that are already in use to control fall armyworms and concluded that it is the future for pest detection on the farm.

This research [45] aims to carry out an in-vitro experiment on badgers in order to assess the different usual infections in a non-invasive way and at reduced cost. The authors analyzed the ability of an electronic nose to identify an infection in cattle using a small amount of serum. The data were studied by linear discriminant function analysis (DFA) and principal component analysis. According to the researchers, without exception, the electronic nose succeeded in distinguishing sick animals and controls from 3 weeks after infection.

In study [46], the damages of Semanotus bifasciatus were studied by combining gas chromatography and mass spectrometry (GC-MS) with the electronic nose. ANNOVA partial least squares regression (APLSR) was used to analyze the relationships between electronic nose response and VOCs. Principal component analysis (PCA), and a grid search support vector machine (GS-SVM) based on six different features obtained from the data collected by the electronic nose to identify the duration of the infestation of pests. Thus, the combination GS and SVM made it possible to predict the duration of the infestation by Semanotus bifasciatus. The results obtained made it possible to identify the adjustment correlation coefficients of the calibration set and the set validation which were 0.9987 and 0.9980. It could be concluded, like a similar study [47]–[49], that electronic nose is a technology capable of identifying trunk borer infestation and pest control.

3.3.3. Environment-oriented applications

An investigation was made in [50] to demonstrate the applications of e-nose on drones in order to explore their use opportunities in the fields of precision agriculture, security, and environmental monitoring. Their methodology was to install an electronic nose based on gas sensing materials like six single-walled carbon nanotubes (SWCNT) and diverse types of polymers. The all-sensor responses from different environmental situations were clearly distinguished. According to them, if they collect enough characteristic odor data from various places into the database, they could identify irregular situations when a new data pattern shows a difference from the database.

The aim of the research [51] was to propose an analysis on the monitoring of foul odors in farms with gas recognition tools such as the electronic nose (e-nose) for the collection and analysis of odors from farms. To realize their goal, the electronic nose was developed in the laboratory and based on eight gas sensors. Hierarchical cluster analysis and principal component analysis were used to study and visualize the odor profile of the samples. Hydrogen sulfide, ammonia and volatile organic compounds were detected and classified in real time. Ammonia gas has primarily been found and identified as the biggest source of bad odors in chicken coops. This study, like others [52], concludes the feasibility of real-time monitoring of odors in outdoor applications.

A small flying electronic nose system was proposed in [53] with the purpose of detecting nitrogen dioxide (NO2) and other hazardous chemical compounds outdoors. To realize this flying electronic nose, a DJI Matrix 100 drone was used with embedded AlphaSense electrochemical MOS sensors. The experimental result of this work presents the detection of NO2 coming from agricultural machinery in a 100-m2 area over 10–12 hours for two days. The data collected were used to generate an NO2 concentration map via interpolation of the values obtained after flying around the emission source.

4. CONCLUSION

The study carried out summarizes the main areas of research on electronic nose applications in the agricultural field. This would allow managers who play a leading role in agricultural monitoring to better guide their choices and investments. Based on this analysis, we observed the search trend on electronic nose agriculture in the last few years. This could be justified by the growing development of agricultural precision and the automation of agricultural monitoring. This joint bibliometric study on Scopus and WoS shows us a similarity between the overall trends of the two databases. However, our results show that WoS indexes more agricultural journals than Scopus. As contributions, our work showed that as of 2019, research on electronic noses has stagnated and may be an effect of the COVID-19 pandemic. However, strategies to revive research work are being implemented by several states such as the United States and China, major researchers in this field. We have also highlighted principal component analysis, like the main analysis method used with electronic nose technology to reduce the sensor array and discriminate volatile organic compound. Then, through our scientific contributions, we observe that there is very little research work in Africa on electronic noses. Strategic decisions should therefore be taken to facilitate the study and deployment of e-noses in West Africa specifically

In the agricultural field, some works were achieved on different varieties of plants to detect diseases or plant damages with very good results. However, less research was carried out to directly identify animals in crops, like pests. Some work should be done in this field to permit the early detection of pests on farms, therefore before first damages. Also, a few papers were published on environmental monitoring using electronic noses in agriculture. This can be explained by the low air pollution in agricultural areas. But in the near future, several works will study the use of electronic noses with unmanned aerial vehicles to control air on farms. Finally, it can be noted that there is almost no work on soil quality using electronic noses. This represents an exploratory field for e-nose applications in agriculture.

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