E-Tongues/Noses Based on Conducting Polymers and Composite Materials

Subjects: Materials Science, Biomaterials

Contributor: David Iglesias

Intrinsic conducting polymers (CPs) have excellent electrochemical characteristics, such as tailored electrical conductivity by electronic doping, high environmental stability, and biocompatibility. This entry intend to overview the use of conducting polymers (CPs), extensively studied due to their high versatility and electrical properties, as chemical sensor arrays in electronic tongues and noses. Their performance in terms of sensitivity and other parameters will be studied based on the characteristic features of common conducting polymers, such as electrical conductivity and nanostructured morphology. Furthermore, the application of electronic devices in commercial prototypes will also be included here.

Keywords: conducting polymers ; electronic tongues ; electronic noses ; chemometric ; discrimination ; analysis

1. Introduction

In the last decades, intrinsic conducting polymers (CPs) have attracted wide attention due to their excellent electrochemical characteristics, such as tailored electrical conductivity by electronic doping, high environmental stability, and biocompatibility. Their electrical and optical properties establish them as excellent candidates for chemical sensing applications targeting the detection/determination of diverse analytes of interest. In this sense, electrochemical sensors[1][2][3], gas sensing devices[4], and optical sensors[5][6] have been proposed as providing good analytical features in terms of figures of merit (e.g., sensitivity, limits of detection and quantitation, repeatability, reproducibility, linear range, and robustness). In addition, the modulation of instrumental conditions during the electrodeposition process[7], spin coating[8], or sequential solution polymerization technique[9][10] allows precise control over the thickness and morphology of the resulting conducting coating. This advantage is particularly important in the development of electrochemical and gas sensors[11][12][13].

In this regard, nanostructures can also be conveniently tailored, leading to analytical sensing improvements [11]. In addition to their morphology, their electrochemical properties can be customized by electronic doping (*p* or *n*) extensively reported in the bibliography[14][15]. As an illustrative example, the *p*-doping of PPy is shown in **Figure 1**. In the first stage, a radical cation is formed by the oxidation of the polymer, inducing a local deformation within the polymer chains, leading to the formation of intermediate electronic states between the conducting and valence band. Subsequently, the polymer can be re-oxidized, increasing the number of charge carriers[16].

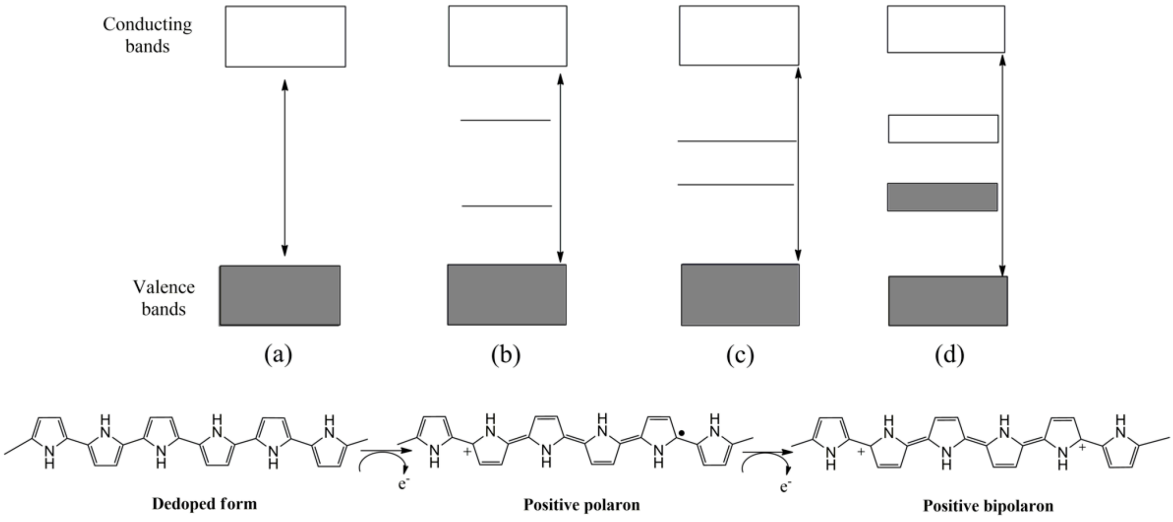

Figure 1. Schematic representation of p-doping process of PPy and structure of electronic bands in different electronic states: (**a**) de-doped, (**b**) polaron, (**c**) bipolaron, (**d**) bipolaron coupling.

This is the reason why the electrochemical characteristics of the conducting polymers, such as electrical conductivity, can be modulated by electronic doping. This characteristic feature allows the employment of conducting polymers in several applications previously mentioned, such as electrochemical transducers in sensor devices, electrochromism, solar cells, batteries and supercapacitors, among others, proving their versatility in comparison with other electrode materials. Furthermore, the entrapment of enzymes within the polymeric layer may increase the selectivity of the overall system. In this sense, several examples, including horseradish peroxidase[17], tyrosinase[18], and glucose oxidase[19] can be found in the literature.

Despite the high number of intrinsic conducting polymers present in the bibliography, great attention was focused on polythiophene and the corresponding derivatives, as well as on polyaniline and polypyrrole (**Figure 2**).

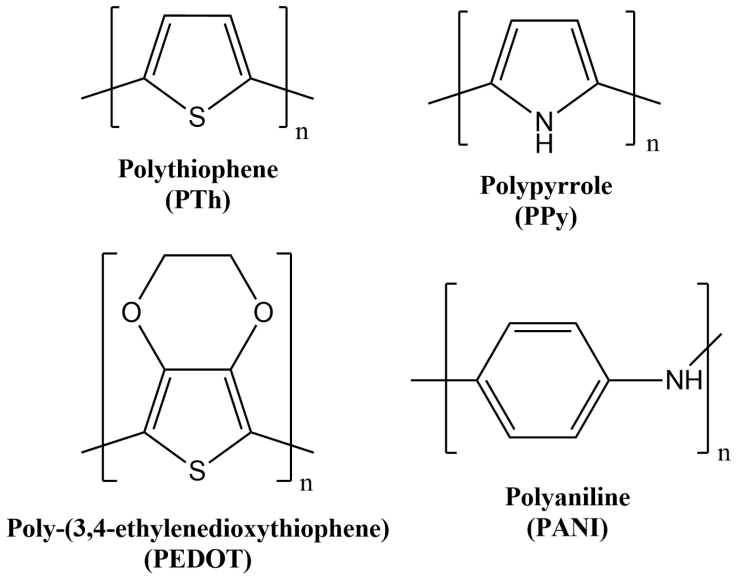

Figure 2. Chemical structure of the most relevant intrinsic conducting polymers.

1.1. Polythiophene and Derivatives

Polythiophene (PTh) have several electroactive properties, such as the remarkable ability for doping/de-doping and high electrical conductivity, which makes them excellent choices for electrochromic supercapacitors and electrochemical applications[20]. Nonetheless, high potentials are required to oxidize the unsubstituted thiophene ring, which can induce the overoxidation of the resulting polymeric film. The inclusion of functional groups in the thiophene monomer leads to a significant reduction of the potentials required for the oxidation due to the presence of electron donor inductive effects[21][22]. Among all the polythiophene derivatives, poly-(3,4-ethylenedioxythiophene) (PEDOT) raised based on its low oxidation potential, which provides a wide oxidation potential window. Hence, the direct electrochemical sensing of different electroactive species can be performed using PEDOT-based electrochemical devices[23][24]. Moreover, the entrapment of biological species onto PEDOT films by several procedures, such as sinusoidal current[25], sinusoidal voltages[26], and drop casting[27] has been achieved.

1.2. Polyaniline

Polyaniline (PANI) is constituted by three ideal oxidation states: leucoemeraldine (reduced form), emeraldine (half-oxidized state), and pernigraniline (fully oxidized state)[28]. The reversible redox conversion between emeraldine base, non-conducting form, to emeraldine salt, conducting form, has been exploited in several electronic devices, e.g., gas sensors, supercapacitors, electrochromic devices, and electrochemical sensors[29][30][31][32]. Regarding electrochemical devices, the electroactivity of polyaniline film plays a relevant role. Low electroactivity of the polyaniline film at neutral and basic electrolytic media can be found, which can be ascribed to the deprotonation of emeraldine salt at higher pH. Polyaniline composites were developed and used for electrochemical sensing to avoid the deprotonation of the conducting polymer backbone. In this sense, self-doped polyaniline-based devices showed electroactivity at neutral media[33][34][35].

1.3. Polypyrrole

Polypyrrole (PPy) is a versatile conducting polymer, characterized by redox properties, high electrical conductivity, and reversible redox switching[36]. The redox conversion of neutral form (yellow) to oxidized form (black grey) is useful for electrochromic applications[37]. The electrochemical performance of polypyrrole composites towards several compounds

for electrochemical and gas sensors is also reported in several review papers[38][39][40]. Furthermore, the entrapment of several enzymes in conducting polypyrrole films to design biosensor devices is also reported in the bibliography[41][42][43].

Based on the previous subsections, the feasible employment of these conducting polymers in complex and high demanding sensing devices, such as electronic tongues (E-tongues) and noses (E-noses), is evident.

1.4. Electronic Systems: Electronic Tongues and Noses

Electronic systems (E-tongues/noses) emerged during the beginning of the 21st Century as useful low-time consuming tools to obtain qualitative and quantitative information about several biological, pharmaceutical, and food samples. Currently, the demand for these devices has been largely increasing in the last years. The terms electronic “tongue” or “nose” arose due to their mimicking properties of taste and smell senses, respectively. To illustrate their growing scientific interest, the number of reports related to their development published per year is shown in **Figure 3**.

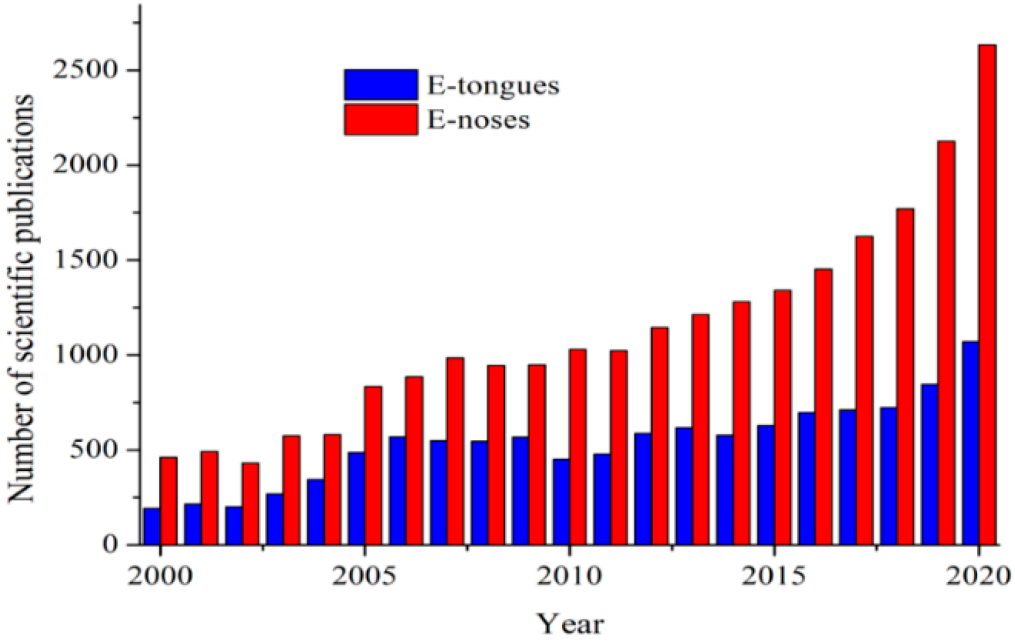

Figure 3. Number of scientific publications containing “electronic tongues” (E-tongues) and “electronic noses” (E-noses) terms published per year. Information obtained from Science Direct database (2021).

E-tongues/noses are mainly constituted by two blocks: a sensing unit, able to produce signals from target chemical species, and their processing part usually based on multivariate calibration methods. The latter permits the discrimination of samples, control of chemical adulteration (qualitative analysis), and correlation between experimental results and chemical parameters (quantitative analysis) by monitoring several features of the target samples[44][45][46][47][48].

2. Electronic Tongues (E-Tongues) Based on CPs

2.1. Sensing Unit: Electrochemical Sensors

The sensing mechanism of conducting polymer-based electrochemical devices has been deeply studied in different pieces of research[49][50]. As an illustrative example, the electrochemical oxidation of ascorbic acid and dopamine using PEDOT-modified sensors in a neutral medium was evaluated. Attractive ionic forces between ascorbate, usually found at neutral medium, and the conducting layer was proposed, leading to an electrocatalytic effect for ascorbic acid oxidation. On the other hand, a repulsive interaction between dopamine and the p-doped conducting film was established[51]. Therefore, the PEDOT sensor allows the simultaneous voltammetric determination of both analytes in neutral medium (**Figure 4**).

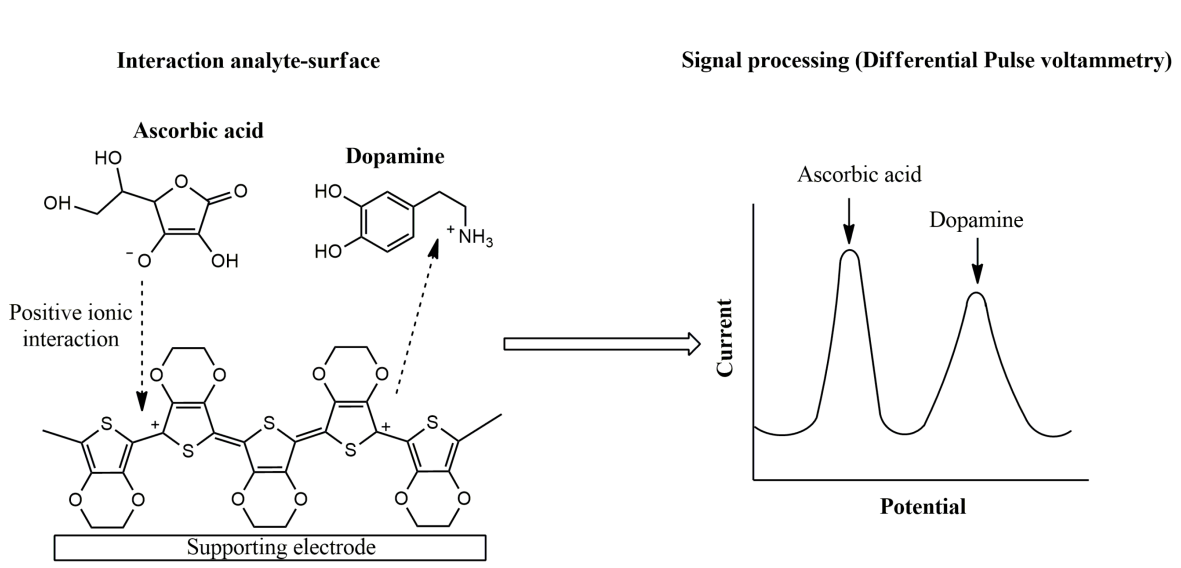

Figure 4. Proposed mechanism for ascorbic acid and dopamine interaction using PEDOT-modified electrodes.

The interaction between the polymeric backbone and the target analyte was also reported for other heterocyclic conducting polymers, such as 3-amino-5-mercapto-1,2,4-triazole[52][53], polyaniline[54], and poly-(N-dimethylaniline)[55].

In addition to their doping properties, the inclusion of redox mediators in the conducting film may improve the electrochemical performance of the resulting devices for sensing diverse analytes of interest. In this regard, several electrochemical sensors employed in electrochemical assays in buffer and real matrices are listed in **Table 1**.

Table 1. Electrochemical sensors based on polythiophene (PTh), poly-(3,4-ethylenedioxythiophene) (PEDOT), polyaniline (PANI), and polypyrrole (PPy) currently reported in literature.

Electrochemical Device	Analyte	Working Media	Sample	Analytical Parameters		Ref.
				LD (µM)	LR (µM)	
PTh						
MWCNT/PTh/Pt	BPA	PBS pH 7.5	Water	0.009	0.05–0.4	[56]
MnO_2/PTh/rGO/GCE	MP	PBS pH 7	Human urine and blood	0.0057	0.5–10	[57]
GO-4-ATP-Au-PTh/Au GCE	Nicotine	PBS pH 7	Serum, urine, cigarette	0.17	1.0–30	[58]
PTh-AgBr	Glucose	NaOH	Human blood plasma	0.31	4–5000	[59]
PTh-Ag/GCE	L-Tryp	PBS pH 7	Soybeans extract	0.020	0.2–400	[60]
PEDOT						

Electrochemical Device	Analyte	Working Media	Sample	Analytical Parameters		Ref.
				LD (μM)	LR (μM)	
PEDOT/IL/GCE	DA	PBS pH 7.4	Human urine	0.033	0.2–328	[61]
UiO-66-NH_2@PEDOT/GA/GCE	PCMC	ABS pH 6	Tap water	0.2	0.6–18	[62]
PEDOT/AG/GCE	AC	PBS pH 7	Local tablets	0.041	0.15–5881	[63]
Cu_2O/PEDOT/MWCNT	Glucose	NaOH	Human blood serum	0.04	0.495–374	[64]
GC/PEDOT-AuNPs-SV	CA	PBS pH 7	Juice	4.24	10–1000	[65]
PEDOT-Tyr/SNG-C	CA	PBS pH 7	Wine, beer	4.33	10–300	[66]
PEDOT/PEDOT-SH/Au	Nitrite	PBS pH 6.9	Tap water, milk	0.051	0.15–1000	[67]
PEDOT/Au	UA	PBS pH 6.6	Milk	7.0	6–200	[68]
GCE/PEDOT-MC/AgNPs	Rutin	PBS pH 3	Tablets	0.0035	0.005–0.5	[69]
Pt/PEDOT-PBNPS	H_2O_2	ABS pH 5.5	Human blood	1.4	5–1000	[70]
		PANI				
Co_3O_4@PANINFs/GCE	Glucose	PBS pH 7.4	Human serum	60	100–8000	[71]
TiO_2@PANI@Au/GCE	Hydrazine	NH_3/NH_4^+ pH 9	Power plant sewage	0.15	0.9–1200	[72]
PANI/SnO_2/GCE	Nitrite	PBS pH 6	-	0.04	0.12–7777	[73]
GCE/PANI-Fe_3O_4	DA	PBS pH 7	Water	0.176	0.2–2.4	[74]
GCE/PANI-NiO	DA	PBS pH 7	Water	0.166	0.2–2.4	[74]

Electrochemical Device	Analyte	Working Media	Sample	Analytical Parameters		Ref.
				LD (μM)	LR (μM)	
α-Fe_2O_3/PANI/GCE	UA	PBS pH 7	Human urine	0.038	0.01–5	[75]
NiO-NPs@PANINS/SPE	Glucose	NaOH	Human blood serum	0.06	1–3000	[76]
MeGO/PANI	AA	PBS pH 7.4	-	2.0	8–5000	[77]
		PPy				
Fe_3O_4@PPy/MWCNTs/GE	AT	BR pH 4	Serum, tablets	0.0230	0.0314–201	[78]
AuNP/PPy/GCE	L-dopa	PBS pH 7	Urine	0.075	0.1–6.0	[79]
PDA/PPy/GCE	UA	PBS pH 8	Human serum, urine	0.11	0.5–40	[80]
PGE/CuO-NPs/PPy	TR	PBS pH 8.5	Tablets	0.001	0.005–380	[81]
PPy:LAC	Lactate	KNO_3	Human tear, rat blood	81.0	100–10,000	[82]
AuCu/PPy/Cu-TCCP	H_2O_2	PBS pH 8	Medical H_2O_2 solution	0.0067	0.71–24,100	[83]

AA: ascorbic acid; ABS: acetic buffer solution; AC: acetaminophen; AT: atorvastatin; ATP: adenosine triphosphate; BPA: bisphenol A; BR: Britton-Robinson; CA: caffeic acid; CuO-NPs: copper oxide nanoparticles; DA: dopamine; PTh: polythiophene; GA: graphene aerogel; GCE: glassy carbon electrode; IL: ionic liquid; LAC: lactate; LD: limit of detection; LR: linear range; L-Tryp: L-tryptophan; MC: mesoporous carbon; MP: methyl parathion; MWCNT: multi-walled carbon nanotubes; PANI: polyaniline; PANINS: polyaniline nanofibers; PBNPS: Prussian blue nanoparticles; PBS: phosphate buffer solution; PCMC: p-chloromethylcresol; PEDOT: poly-(3,4-ethylenedioxythiophene); PGE: pencil graphite electrode; PPy: polypyrrole; rGO: reduced-graphene oxide; SPE: screen-printed electrode; SV: sinusoidal voltage; TCCP: meso-tetra-(4-carboxyphenyl)-substituted porphyrins; TR: tramadol; and UA: uric acid.

2.2. Analytical Application of E-Tongues

Electronic tongues have been successfully applied in the analysis of a wide range of samples. Their multiple applications in different ambits employing potentiometric and/or voltammetric sensor arrays were overviewed by many researchers[84][85][86][87].

The preliminary studies regarding electronic tongues containing conducting polymers developed by C. Mattoso and coworkers involves the use of ultrathin layers of PPy electrodeposited and their application in the distinction of some beverages[88][89][90]. One year later, De Saja developed an E-tongue by using PPy, PTh, and PANI coatings as voltammetric sensor arrays. Each one provided characteristic voltammetric signals, increasing the cross-selectivity of the

resulting device and discriminating solutions with different tasting properties[91]. Moreover, conducting polymers were tested as well for qualitative analysis of tea and coffee samples and the quantitative determination of specific analytes contained in green Korean tea[92]. Notably, subsequent sensor arrays composed by conducting electrodeposited polymer coatings are relevant for food analysis at industrial scale. **Table 2** shows several electronic tongues employed in electroanalysis of some foodstuffs.

Table 2. Electronic tongues containing sensors based on conducting polymer coatings applied in the analysis of food samples.

Sensor Array		Sample	Use	Multivariate Calibration	Ref.
No CP Sensor	CP Sensor				
SNG-C	PEDOT/Pt	Musts	Discrimination of samples collected at different ripening times	PCA iPLS PLS	[93]
-	PEDOT/Pt	Red wines	Classification of different samples and origin	PCA PLS	[94]
Pt Au	PEDOT/Pt	Fruit juice	Discrimination between samples from different fruits	PCA PLS-LDA	[95]
IDE PA6/IDE	PA6/PANI/IDE (0.25–5.0% PANI)	Bovine milk	Discrimination of samples according to tetracycline residue content	PCA	[96]
CE AuCE rGO-CE rGO-AuCE	PANI-CE PANI-AuCE	Vinegar, sugar	Multiflavor detection	PCA	[97]
C/SPE NiO/C/SPE MWCNT/C/SPE SWCNT/C/SPE Pt	PANI/C/SPE	Red wine	Phenolic content	PCA	[98]
SWCNT/SPCE MWCNT/SPCE	PPy-DSA/SPCE	White wine	Discrimination according to varietal origin	PCA LDA	[99]
CPE-CoPc CPE-$LuPc_2$ CPE-$LuPc_2$	PPy-dopant/Au Dopant: SO_4, DSA, FCN, AQDS, PWA, TSA	Red wine	Evaluation of chemical adulteration	PCA PLS	[100]

Sensor Array		Sample	Use	Multivariate Calibration	Ref.
No CP Sensor	CP Sensor				
$GdPc_2$/CSPE $DyPc_2$/CSPE CSPE	PPy-dopant/CSPE Dopant: FeCN, NP, Mo	Beef	Determination of ammonia and putresceine	PCA PLS-LDA	[101]
-	PPy- dopant/Pt Dopant: DSA, H_2SO_4, FCN, AQDS, PWA, TSA	Beer	Evaluation of bitterness and alcoholic strength	PCA PLS	[102]
-	PPy-dopant/Pt Dopant: FCN, NP, PWA, H_2SO_4, MO, AQS	Olive oil	Evaluation of bitterness	PCA PLS	[103]
-	PPy-dopant/SPCE Dopant: DSA, SO_4, FCN	Wine	Classification of wines according to vintage year	PCA LDA	[104]
Graphite-epoxy PtNPs CuNPs	PANI PPy	Wine	Classification of wines and recognition of the oxygenation effect	PCA	[105]

AQDS: anthraquinone-2,6-disulfonic acid, disodium salt; AQS: anthraquinone-2,6-disulfonic acid; CNT: carbon nanotubes; CoPc: cobalt phthalocyanine; CPE: carbon paste electrode; CuNPs: copper nanoparticles; DSA: sodium 1-decanesulfonate; FCN: potassium hexacyanoferrate (II); IDE: interdigitated electrodes; LDA: linear discriminant analysis; LuPc2: lutetium bis-phthalocyanine; MO: sodium molybdate; MWCNT: multi-walled carbon nanotubes; PA6: polyacrilamide; PANI: polyaniline; PCA: principal component analysis; PEDOT: poly-(3,4-ethylenedioxythiophene); PLS: partial least squares regression; PPy: polypyrrole; PWA: phosphotungstic acid; PtNPS: platinum nanoparticles; rGO: reduced-graphene oxide; SNG-C: sonogel-carbon; SPCE: screen-printed-carbon electrode; SPE: screen-printed electrode; SWCNT: single-walled carbon nanotubes; and TSA: p-toluenesulfonic acid.

3. Electronic Noses (E-Noses) Based on CPs

3.1. Sensing Unit: Chemiresistors

In principle, three types of sensing units can be employed in gas sensing: chemiresistors, quartz crystal microbalance gravimetry, and optical sensors[106]. Among all of them, the first one is, by far, the most employed unit in electronic noses, and thus, this review will be focused on chemiresistors as the sensing unit.

The sensing performance of chemiresistor-based conducting polymers has been widely reported in bibliography. In brief, after exposing the conducting film to gases, the resistance changes depending on the initial concentration of the flowing gas. The overall resistance (S) measured with the p-doped polymeric device was calculated by the ratio between the resistance in air (R_a) and the resistance in the presence of the flowing gas (R_g) by using the following equation[107].

$$S = \frac{|R_g - R_a|}{R_a} \times 100 \quad (1)$$

The sensing mechanism of p-doped conducting polymers towards different pollutants is overviewed in several review papers[108][109][110][111] and shown in **Figure 5**. The target gas can act as an electron donor of the conducting polymer layer, leading to a decrease in the number of holes by electron-hole combination, and thus, increase the charge resistance. On the other hand, electrons from the conducting band of the polymer can be removed by an electron-acceptor compound, leading to the increase in the number of holes, and, hence, decrease the electrical resistance.

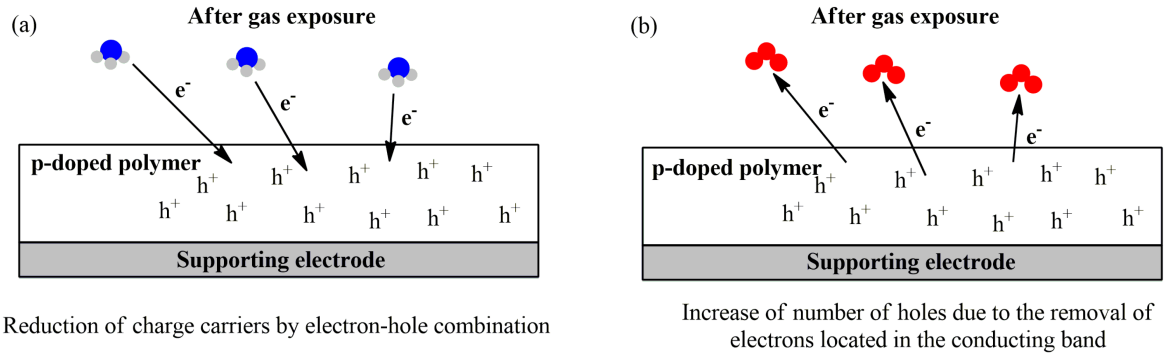

Figure 5. Overall mechanism of gas sensing using a reducing gas (NH_3) (**a**) and an oxidant gas (O_3) (**b**) as examples.

The p-doped polymer resistance changes depending on the nature of the target analyte: oxidant gases, such as NO_2 and O_3, induce an increase in the number of major charge carriers, decreasing the resistance (**Figure 5**b). Reducing gases, such as NH_3, CO, and H_2S, induce the opposite effect by decreasing the charge carriers of the conducting film (**Figure 5**a)[112].

The protonation/deprotonation of the conducting layer due to the vapor exposure is also reported in the literature for some conducting polymers, such as PANI[113][114][115]. **Figure 6** illustrates a possible interaction between ammonia, a reducing gas widely employed as model analyte, and PANI.

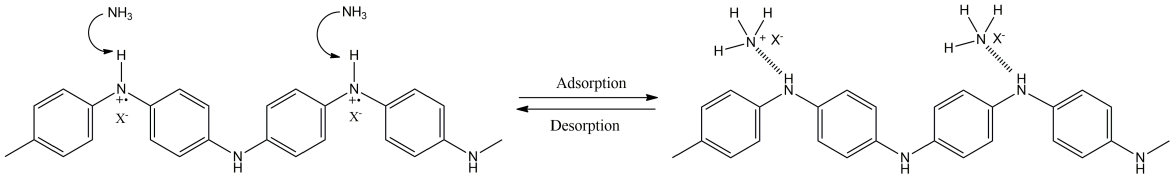

Figure 6. Possible interaction mechanism between ammonia and PANI.

As it can be observed in the previous figure, PANI can be deprotonated under ammonia exposure, leading to the de-doped state of PANI. This process is reversible, and thus, PANI can be protonated again, leading to the desorption of ammonia. The performance of some chemiresistors based on conducting polymers, in terms of concentration detected, response and recovery times, are shown in **Table 3**.

Table 3. Chemiresistors based on polythiophene (PTh), poly-(3,4-ethylenedioxythiophene) (PEDOT), polyaniline (PANI), and polypyrrole (PPy).

Gas Sensor Device	Target Gas	Range (ppm)	Sensing Performance			Ref.
			Gas Conc. (ppm)	Recovery Time (s)	Response Time (s)	
SnO_2/PTh	NO_2	10–200	10	-	2.07	[116]
P3CT/CNT	NMPEA	0.004–0.032	0.004	40	20	[117]
PEDOT:PSS/$FeCl_3$	NH_3	0.2–200	0.5	-	20	[118]

Gas Sensor Device	Target Gas	Range (ppm)	Sensing Performance			Ref.
			Gas Conc. (ppm)	Recovery Time (s)	Response Time (s)	
WO_3-PEDOT:PSS	LPG	500–3000	500	54	29.4	[119]
PANI/PVDF	NH_3	0.2–5	0.2	235	174	[120]
PANI/SnO_2	NO_2	5–55	37	25	17	[121]
SnO_2/rGO/PANI	H_2S	0.05–10	2	78	82	[122]
PANI-NF	LPG	100–1000	700	200	50	[123]
PPy/rGO	NH_3	1.0–4.0	1.0	300	60	[124]
PPy thin film	NO_2	10–100	10	374	218	[125]
PPy nanoribbons	CH_3CH_2OH	-	100	31	2	[126]
PPy-Ag	CH_3COCH_3	25–600	580	150	175	[127]
PPy-CNT	H_2	1–100	10	-	>1.0	[128]

CNT: carbon nanotubes; LPG: liquified petroleum gas; NF: nickel ferrite; NMPEA: n-methylphenethylamine; P3CT: poly[3 -(6-carboxyhexyl)thiophene-2,5-diyl]; PANI: polyaniline; PEDOT: poly-(3,4-ethylenedioxythiophene); PPy: polypyrrole; PSS: poly(styrenesulfonate); PTh: polythiophene; PVDF: polyvinylidene; and r-GO: reduced-graphene oxide.

3.2. Analytical Application of E-Noses

Among the multiple possible applications of E-noses, the early diagnosis of diseases and the evaluation of food quality in a non-invasive manner are the most relevant for society. Importantly, electronic nose devices based on conducting nanocomposites have proved their suitability in both scenarios during the last decade [129][130][131][132].

Despite its high interest currently, investigations of the role of conducting polymers in electronic noses started in the previous century, with the development of PPy, PTh, and PANI derivatives to detect alcoholic volatile compounds[133]. However, new discoveries have been carried out at the beginning of this century, leading to great improvements in the development of these devices. In this regard, Stella and coworkers developed an E-nose system based on PEDOT, PANI, and PPy coatings for the distinction of three Italian olive oils by using their aromatic substances content as a differentiating parameter[134]. Contrarily, other authors have vastly explored the role of several dopants. For example, Barisci et al. developed gold tracks supported on silicon chip coated with PPy doped with 12 different chemical compounds to detect aromatic hydrocarbons, benzene, toluene, ethylbenzene, and xylene[135]. In spite of the lack of concise explanations, the authors must be praised for the wide spectrum of polymers assayed. In fact, the evaluation of different dopants in CPs seems to be the quintessence of a great number of pieces of research. Particularly, PANI coatings with different doping agents are commonly reported in bibliography as sensor arrays in E-nose devices to monitor several parameters in foodstuffs and human body fluids[136][137][138]. **Table 4** shows some illustrative examples recently reported in the literature.

Table 4. Electronic noses based on polyaniline (PANI) films applied for analytical purposes in the last decade.

PANI Sensor Array	Sample	Use	Multivariate Calibration	Ref.
PANI-dopant/IDGEs Dopant: CSA, DBSA, HCl	Strawberry Grape Apple	Discrimination of samples according to aromatic substances	PCA	[139]
PANI-HCl/PGIEs PANI-HCl/IDEs	Strawberry Grape Apple	Detection of different aromas	PCA	[140]
PANI-dopant/IDGEs Dopant: HCl, TSA, CSA, MSA	Cow's estrus	Determination of estrus times of cows	PCA	[141]
PANI-dopant/IDEs Dopant: HCl, TSA, CSA, MSA	Bananas	Monitoring of bananas ripeness	PCA	[142]
PANI-dopant/PGIEs Dopant: CSA, HCl, DBSA	Gummy candies	Monitoring of aromas during candy storage	PCA	[143]
PANI-CSA/Chitosan PANI-DBSA/TiO_2 PANI-DBSA/CNT	Simulated human breath	Preliminary diagnoses of kidney disease	PCA LDA	[144]
PANI/AuNPs	Human breath	Early diagnoses of renal diseases	PCA LDA	[145]
PANI-dopant/MWCNT PANI-dopant/GO Dopant: CSA, DBSA, HCl	Essential oils	Determination of quality of essential oils	PCA	[146]

CSA: camphorsulfonic acid; DBSA: dodecylbenzenesulfonic acid; GO: graphene oxide; IDE: interdigitated electrode; MSA: methanesulfonic acid; MWCNT: multi-walled carbon nanotubes; PANI: polyaniline; and TSA: p-toluene sulfonic acid.

4. Future perspectives: integration of E-tongues and E-noses in commercial systems

It is not ambitious to think that the analytical applications of E-Tongues/Noses possess a great impact, not only in the foodstuff ambit but also in the health and environmental sector. Besides, this impact is rising sharply, reflecting the great need in society for these devices. Therefore, their implementation in commercial devices is exceedingly pursued by many sensor companies. Currently, there are some examples of its commercialization.

4.1 Commercial prototypes of E-tongues

Concerning E-tongues, Alpha M.O.S and Insent Inc. offers two models (αAstree and TS-5000Z, respectively) that have been used in the evaluation of food quality in the last decade[147][148][149][150][151]. Other laboratory prototypes were also employed for pharmaceutical analysis, providing very satisfactory results, as those obtained with commercial systems[152].

4.2 Commercial prototypes of E-noses

Regarding E-noses, a commercial system containing several conducting polymers as sensor arrays (Cyranose 320®), offered by Sensigent, was employed in the screening of several diseases (breast and lung cancer[153][154][155], asthma[156][157] and amyotrophic lateral sclerosis[158], among others), identification of foodstuffs (rice, wines[159] and fruits[160]) and classification of road asphalt samples[161][162]. Additionally, fecal VOCs can be inspected as well, informing about the microbial enterotype of infants[163]. Other companies also supply E-noses. For example, AromaScan A32S® (Osmetech Inc.) provides useful information about the diagnose of urban trees, being able to discriminate VOCs from healthy and decay woody samples[164] and the assessment of the quality of catfish meat[165]. In this work, off-flavour in catfish filets can be identified from good-flavour ones by means of PCA. Notably, the new device tested displayed promising features for the analysis of commercial beverages[166].

4.3 Final remarks: challenges of electrochemical/gas sensing devices

Despite the excellent analytical results provided at laboratory scale in food, pharmaceutical and medical sectors, only some timid examples can be found commercially available. In our modest opinion, the inclusion of CPs and their development may pave the way to keep growing and reach the desired applicability of E-tongues and E-noses systems. Nowadays, in order to climb up into higher technological readiness levels (TRLs), the developed devices must be able to perform reliable, robust, fast, accurate and in-situ measurements using diverse samples, by using a non-complex, low cost and portable instrumentation. The stability of the conducting coatings is another issue to take into account, since the repeatability of the responses provided with the devices can be affected. The conducting film may be passivated after performing successive electrochemical assays, as well as film overoxidation can take place at high potentials. Furthermore, stability can be affected by swelling/deswelling phenomena. With the aim to minimize these factors, several parameters, including analyte concentration, film characteristics (e.g thickness and morphology) and instrumental conditions should be carefully controlled. Further research in this sense is under study to accomplish all the commercial requirements mentioned.

References

1. Bruna Hryniewicz; Elisa Orth; Marcio Vidotti; Enzymeless PEDOT-based electrochemical sensor for the detection of nitrophenols and organophosphates. *Sensors and Actuators B: Chemical* **2018**, *257*, 570-578, 10.1016/j.snb.2017.10.162.
2. Nahid Shoaie; Maryam Daneshpour; Mostafa Azimzadeh; Sara Mahshid; Seyyed Mehdi Khoshfetrat; Fatemeh Jahanpeyma; Alieh Gholaminejad; Kobra Omidfar; Mehdi Foruzandeh; Electrochemical sensors and biosensors based on the use of polyaniline and its nanocomposites: a review on recent advances. *Microchimica Acta* **2019**, *186*, 465, 10.1007/s00604-019-3588-1.
3. Aminur Rahman; Pankaj Kumar; Deog-Su Park; Yoon-Bo Shim; Electrochemical Sensors Based on Organic Conjugated Polymers. *Sensors* **2008**, *8*, 118-141, 10.3390/s8010118.
4. Yung Cheng Wong; Bee Chin Ang; A. S. M. A. Haseeb; Aainaa Aqilah Baharuddin; Yew Hoong Wong; Review—Conducting Polymers as Chemiresistive Gas Sensing Materials: A Review. *Journal of The Electrochemical Society* **2019**, *167*, 037503, 10.1149/2.0032003jes.
5. Yu Lin; Yongmin Zhao; Qian Xin; Chunping Jiang; Aimin Song; Electrical control of the optical dielectric properties of PEDOT:PSS thin films. *Optical Materials* **2020**, *108*, 110435, 10.1016/j.optmat.2020.110435.
6. Irma Zulayka Mohamad Ahad; Sulaiman Wadi Harun; Seng Neon Gan; Sook Wai Phang; Polyaniline (PAni) optical sensor in chloroform detection. *Sensors and Actuators B: Chemical* **2018**, *261*, 97-105, 10.1016/j.snb.2018.01.082.
7. Sara A. AlQarni; Mahmoud A. Hussein; Aisha A. Ganash; Anish Khan; Composite Material–Based Conducting Polymers for Electrochemical Sensor Applications: a Mini Review. *BioNanoScience* **2020**, *10*, 351-364, 10.1007/s12668-019-00708-x.
8. Francesco Greco; Alessandra Zucca; Silvia Taccola; Arianna Menciassi; Toshinori Fujie; Hiroki Haniuda; Shinji Takeoka; Paolo Dario; Virgilio Mattoli; Ultra-thin conductive free-standing PEDOT/PSS nanofilms. *Soft Matter* **2011**, *7*, 10642-10650, 10.1039/c1sm06174g.
9. Rui Chen; Shanshan Chen; Yongli Zhou; Zhouyin Wei; Haiyan Wang; Yujie Zheng; Meng Li; Kuan Sun; Yongfang Li; Unsubstituted Polythiophene Film Deposited via In-Situ Sequential Solution Polymerization for Chemo-/Electrochromism. *Macromolecules* **2020**, *53*, 4247-4254, 10.1021/acs.macromol.0c00297.
10. Rui Chen; Kuan Sun; Qi Zhang; Yongli Zhou; Meng Li; Yuyang Sun; Zhou Wu; Yuyang Wu; Xinlu Li; Jialei Xi; et al. Sequential Solution Polymerization of Poly(3,4-ethylenedioxythiophene) Using V2O5 as Oxidant for Flexible Touch

Sensors. *iScience* **2019**, *12*, 66-75, 10.1016/j.isci.2019.01.003.

11. Vessela Tsakova; Renato Seeber; Conducting polymers in electrochemical sensing: factors influencing the electroanalytical signal. *Fresenius' Journal of Analytical Chemistry* **2016**, *408*, 7231-7241, 10.1007/s00216-016-9774-7.
12. Kangkang Zhou; Kun Dai; Chuntai Liu; Changyu Shen; Flexible conductive polymer composites for smart wearable strain sensors. *SmartMat* **2020**, *1*, e1010, 10.1002/smm2.1010.
13. Yueyue Qian; Chuang Ma; Shupeng Zhang; Juanjuan Gao; Maoxiang Liu; Kangjun Xie; Shuang Wang; Kuan Sun; Haiou Song; High performance electrochemical electrode based on polymeric composite film for sensing of dopamine and catechol. *Sensors and Actuators B: Chemical* **2018**, *255*, 1655-1662, 10.1016/j.snb.2017.08.174.
14. Abhishek Kumar Mishra; Conducting Polymers: Concepts and Applications. *Journal of Atomic, Molecular, Condensate and Nano Physics* **2018**, *5*, 159-193, 10.26713/jamcnp.v5i2.842.
15. Richard Balint; Nigel J. Cassidy; Sarah H. Cartmell; Conductive polymers: Towards a smart biomaterial for tissue engineering. *Acta Biomaterialia* **2014**, *10*, 2341-2353, 10.1016/j.actbio.2014.02.015.
16. Thanh-Hai Le; Yukyung Kim; Hyeonseok Yoon; Electrical and Electrochemical Properties of Conducting Polymers. *Polymers* **2017**, *9*, 150, 10.3390/polym9040150.
17. Mihaela Tertis; Anca Florea; Robert Săndulescu; Cecilia Cristea; Carbon Based Electrodes Modified with Horseradish Peroxidase Immobilized in Conducting Polymers for Acetaminophen Analysis. *Sensors* **2013**, *13*, 4841-4854, 10.3390/s130404841.
18. Huseyin Bekir Yildiz; Salim Caliskan; Musa Kamaci; Abdullah Caliskan; Hasim Yilmaz; l-Dopa synthesis catalyzed by tyrosinase immobilized in poly(ethyleneoxide) conducting polymers. *International Journal of Biological Macromolecules* **2013**, *56*, 34-40, 10.1016/j.ijbiomac.2013.01.031.
19. Jugović, B.; Grgur, B.; Antov, M.; Knežević-Jugović, Z.; Stevanović, J.; Gvozdenović, M.; Polypyrrole-based Enzyme Electrode with Immobilized Glucose Oxidase for Electrochemical Determination of Glucose. *Int. J. Electrochem. Sci* **2016**, *11*, 1152-1161, .
20. Taniya M. S. K. Pathiranage; Dushanthi S. Dissanayake; Crystal N. Niermann; Yixin Ren; Michael C. Biewer; Mihaela C. Stefan; Role of polythiophenes as electroactive materials. *Journal of Polymer Science Part A: Polymer Chemistry* **2017**, *55*, 3327-3346, 10.1002/pola.28726.
21. L. Groenendaal; G. Zotti; P.-H. Aubert; S.M. Waybright; J.R. Reynolds; Electrochemistry of Poly(3,4-alkylenedioxythiophene) Derivatives. *Advanced Materials* **2003**, *15*, 855-879, 10.1002/adma.200300376.
22. C. Zanardi; Fabio Terzi; R. Seeber; Polythiophenes and polythiophene-based composites in amperometric sensing. *Analytical and Bioanalytical Chemistry* **2012**, *405*, 509-531, 10.1007/s00216-012-6318-7.
23. Guangyuan Xu; Zahraa A. Jarjes; Valentin Desprez; Paul Kilmartin; Jadranka Travas-Sejdic; Sensitive, selective, disposable electrochemical dopamine sensor based on PEDOT-modified laser scribed graphene. *Biosensors and Bioelectronics* **2018**, *107*, 184-191, 10.1016/j.bios.2018.02.031.
24. Danfeng Sun; Hongji Li; Mingji Li; Cuiping Li; Hongli Dai; Dazhi Sun; Baohe Yang; Electrodeposition synthesis of a NiO/CNT/PEDOT composite for simultaneous detection of dopamine, serotonin, and tryptophan. *Sensors and Actuators B: Chemical* **2018**, *259*, 433-442, 10.1016/j.snb.2017.12.037.
25. Juan José García Guzmán; Laura Cubillana Aguilera; Dolores Bellido Milla; Ignacio Naranjo Rodríguez; Cecilia Lete; Jose María Palacios Santander; Stelian Lupu; Development of Sonogel-Carbon based biosensors using sinusoidal voltages and currents methods. *Sensors and Actuators B: Chemical* **2018**, *255*, 1525-1535, 10.1016/j.snb.2017.08.161.
26. Stelian Lupu; Cecilia Lete; Paul Catalin Balaure; Dan Ion Caval; Constantin Mihailciuc; Boris Lakard; Jean-Yves Hihn; Francisco Javier Del Campo; Development of Amperometric Biosensors Based on Nanostructured Tyrosinase-Conducting Polymer Composite Electrodes. *Sensors* **2013**, *13*, 6759-6774, 10.3390/s130506759.
27. Merih Zeynep Çetin; Pinar Camurlu; An amperometric glucose biosensor based on PEDOT nanofibers. *RSC Advances* **2018**, *8*, 19724-19731, 10.1039/c8ra01385c.
28. Mahnoush Beygisangchin; Suraya Abdul Rashid; Suhaidi Shafie; Amir Sadrolhosseini; Hong Lim; Preparations, Properties, and Applications of Polyaniline and Polyaniline Thin Films—A Review. *Polymers* **2021**, *13*, 2003, 10.3390/polym13122003.
29. Hairui Zhang; Jixiao Wang; Xingbin Gao; Zhi Wang; Shichang Wang; The electrochemical activity of polyaniline: An important issue on its use in electrochemical energy storage devices. *Synthetic Metals* **2014**, *187*, 46-51, 10.1016/j.synthmet.2013.10.022.
30. Rajesh Kashyap; Ravi Kumar; Mukesh Kumar; Sachin Tyagi; Dinesh Kumar; Polyaniline nanofibers based gas sensor for detection of volatile organic compounds at room temperature. *Materials Research Express* **2019**, *6*, 1150d3, 10.108

8/2053-1591/ab4e43.

31. Fern M. Kelly; Ludivine Meunier; Cédric Cochrane; Vladan Koncar; Polyaniline: Application as solid state electrochromic in a flexible textile display. *Displays* **2013**, *34*, 1-7, 10.1016/j.displa.2012.10.001.

32. Zondi Nate; Atal A.S. Gill; Ruchika Chauhan; Rajshekhar Karpoormath; Polyaniline-cobalt oxide nanofibers for simultaneous electrochemical determination of antimalarial drugs: Primaquine and proguanil. *Microchemical Journal* **2020**, *160*, 105709, 10.1016/j.microc.2020.105709.

33. Xiaoyu Zhao; Wenlong Bai; Yujia Yan; Yanfei Wang; Juankun Zhang; Core-Shell Self-Doped Polyaniline Coated Metal-Organic-Framework (SPAN@UIO-66-NH2) Screen Printed Electrochemical Sensor for Cd2+ Ions. *Journal of The Electrochemical Society* **2019**, *166*, B873-B880, 10.1149/2.0251912jes.

34. C. Sanchis; M.A. Ghanem; H.J. Salavagione; E. Morallón; P.N. Bartlett; The oxidation of ascorbate at copolymeric sulfonated poly(aniline) coated on glassy carbon electrodes. *Bioelectrochemistry* **2011**, *80*, 105-113, 10.1016/j.bioelechem.2010.06.006.

35. Fatemeh Masdarolomoor; Somayeh Hajizadeh; Mansoor Arab Chamjangali; Peter C. Innis; Novel approach to the synthesis of polyaniline possessing electroactivity at neutral pH. *Synthetic Metals* **2019**, *250*, 121-130, 10.1016/j.synthmet.2019.03.011.

36. Habib Ullah; Anwar-Ul-Haq Ali Shah; Salma Bilal; Khurshid Ayub; Doping and Dedoping Processes of Polypyrrole: DFT Study with Hybrid Functionals. *The Journal of Physical Chemistry C* **2014**, *118*, 17819-17830, 10.1021/jp505626d.

37. Pinar Camurlu; Polypyrrole derivatives for electrochromic applications. *RSC Advances* **2014**, *4*, 55832-55845, 10.1039/c4ra11827h.

38. A. Ramanavičius; A. Ramanavičienė; A. Malinauskas; Electrochemical sensors based on conducting polymer—polypyrrole. *Electrochimica Acta* **2006**, *51*, 6025-6037, 10.1016/j.electacta.2005.11.052.

39. Siddhant Jain; Mohan Singh Mehata; Medicinal Plant Leaf Extract and Pure Flavonoid Mediated Green Synthesis of Silver Nanoparticles and their Enhanced Antibacterial Property. *Scientific Reports* **2017**, *7*, 1-13, 10.1038/s41598-017-15724-8.

40. Krzysztof Maksymiuk; Chemical Reactivity of Polypyrrole and Its Relevance to Polypyrrole Based Electrochemical Sensors. *Electroanalysis* **2006**, *18*, 1537-1551, 10.1002/elan.200603573.

41. Servet Cete; Munise Ozyurt; Ertan Yildirim; Deniz Akin; A novel biosensor with the use of polypyrrole–poly(sodium-4-styrenesulphonate) as a dopant in the determination of glucose. *Chemical Papers* **2019**, *74*, 799-808, 10.1007/s11696-019-00907-6.

42. Joseph G. Ayenimo; Samuel B. Adeloju; Amperometric detection of glucose in fruit juices with polypyrrole-based biosensor with an integrated permselective layer for exclusion of interferences. *Food Chemistry* **2017**, *229*, 127-135, 10.1016/j.foodchem.2017.01.138.

43. Lara F. Loguercio; Anderson Thesing; Pedro Demingos; Carlos D.L. de Albuquerque; Roberta S.B. Rodrigues; Alexandre G. Brolo; Jacqueline F.L. Santos; Efficient acetylcholinesterase immobilization for improved electrochemical performance in polypyrrole nanocomposite-based biosensors for carbaryl pesticide. *Sensors and Actuators B: Chemical* **2021**, *339*, 129875, 10.1016/j.snb.2021.129875.

44. Tais Carpintero Barroso de Morais; Dayvison Ribeiro Rodrigues; Urijatan Teixeira De Carvalho Polari Souto; Sherlan G. Lemos; A simple voltammetric electronic tongue for the analysis of coffee adulterations. *Food Chemistry* **2019**, *273*, 31-38, 10.1016/j.foodchem.2018.04.136.

45. Marta Podrażka; Ewa Bączyńska; Magdalena Kundys; Paulina S. Jeleń; Emilia Witkowska Nery; Electronic Tongue—A Tool for All Tastes?. *Biosensors* **2017**, *8*, 3, 10.3390/bios8010003.

46. Lara Sobrino-Gregorio; Román Bataller; Juan Soto; Isabel Escriche; Monitoring honey adulteration with sugar syrups using an automatic pulse voltammetric electronic tongue. *Food Control* **2018**, *91*, 254-260, 10.1016/j.foodcont.2018.04.003.

47. María José Aliaño-González; Marta Ferreiro-González; Gerardo F. Barbero; Jesús Ayuso; José A. Álvarez; Miguel Palma; Carmelo G. Barroso; An Electronic Nose Based Method for the Discrimination of Weathered Petroleum-Derived Products. *Sensors* **2018**, *18*, 2180, 10.3390/s18072180.

48. Maimunah Mohd Ali; Norhashila Hashim; Samsuzana Abd Aziz; Ola Lasekan; Principles and recent advances in electronic nose for quality inspection of agricultural and food products. *Trends in Food Science & Technology* **2020**, *99*, 1-10, 10.1016/j.tifs.2020.02.028.

49. Limin Lu; Electrochemical Sensor Based on poly(3,4-ethylenedioxy - thiophene) Doped with Transition Metals for Detecting Rutin in Buck Wheat Tea. *International Journal of Electrochemical Science* **2018**, *13*, 2126-2135, 10.20964/2018.02.66.

50. Jorge G. Ibanez; Marina. E. Rincón; Silvia Gutierrez-Granados; M'Hamed Chahma; Oscar Andrés Jaramillo-Quintero; Bernardo A. Frontana-Uribe; Conducting Polymers in the Fields of Energy, Environmental Remediation, and Chemical–Chiral Sensors. *Chemical Reviews* **2018**, *118*, 4731-4816, 10.1021/acs.chemrev.7b00482.

51. V.S. Vasantha; Shen-Ming Chen; Electrocatalysis and simultaneous detection of dopamine and ascorbic acid using poly(3,4-ethylenedioxy)thiophene film modified electrodes. *Journal of Electroanalytical Chemistry* **2006**, *592*, 77-87, 10.1016/j.jelechem.2006.04.026.

52. S. Brillians Revin; S. Abraham John; Simultaneous determination of two important dopamine metabolites at physiological pH by voltammetry. *Analytical Methods* **2012**, *4*, 348-352, 10.1039/c2ay05664j.

53. S. Brillians Revin; Abraham John; Electrochemical sensor for neurotransmitters at physiological pH using a heterocyclic conducting polymer modified electrode. *The Analyst* **2011**, *137*, 209-215, 10.1039/c1an15746a.

54. Limin Yang; Shufeng Liu; Qixiu Zhang; Feng Li; Simultaneous electrochemical determination of dopamine and ascorbic acid using AuNPs@polyaniline core–shell nanocomposites modified electrode. *Talanta* **2012**, *89*, 136-141, 10.1016/j.talanta.2011.12.002.

55. Protiva Rani Roy; Takeyoshi Okajima; Takeo Ohsaka; Simultaneous electroanalysis of dopamine and ascorbic acid using poly (N,N-dimethylaniline)-modified electrodes. *Bioelectrochemistry* **2002**, *59*, 11-19, 10.1016/s1567-5394(02)00156-1.

56. Jun Wan; Yuxiao Si; Chao Li; Kun Zhang; Bisphenol a electrochemical sensor based on multi-walled carbon nanotubes/polythiophene/Pt nanocomposites modified electrode. *Analytical Methods* **2016**, *8*, 3333-3338, 10.1039/C6AY00850J.

57. T. Ramachandran; V. Violet Dhayabaran; Utilization of a MnO2/polythiophene/rGO nanocomposite modified glassy carbon electrode as an electrochemical sensor for methyl parathion. *Journal of Materials Science: Materials in Electronics* **2019**, *30*, 12315-12327, 10.1007/s10854-019-01590-9.

58. Asma Saljooqi; Tayebeh Shamspur; Ali Mostafavi; The electrochemical sensor based on graphene oxide nanosheets decorated by gold nanoparticles and polythiophene for nicotine sensing in biological samples and cigarette. *Journal of Materials Science: Materials in Electronics* **2020**, *31*, 5471-5477, 10.1007/s10854-020-03111-5.

59. Seyyed Alireza Hashemi; Seyyed Mojtaba Mousavi; Sonia Bahrani; Seeram Ramakrishna; Polythiophene silver bromide nanostructure as ultra-sensitive non-enzymatic electrochemical glucose biosensor. *European Polymer Journal* **2020**, *138*, 109959, 10.1016/j.eurpolymj.2020.109959.

60. S. Dheepthi GunaVathana; P. Thivya; J. Wilson; A. Cyrac Peter; Sensitive voltammetric sensor based on silver dendrites decorated polythiophene nanocomposite: Selective determination of L-Tryptophan. *Journal of Molecular Structure* **2020**, *1205*, 109959, 10.1016/j.molstruc.2019.127649.

61. Zhen Song; Ge Sheng; Yige Cui; Mengru Li; Zhiling Song; Caifeng Ding; Xiliang Luo; Low fouling electrochemical sensing in complex biological media by using the ionic liquid-doped conducting polymer PEDOT: application to voltammetric determination of dopamine. *Microchimica Acta* **2019**, *186*, 220, 10.1007/s00604-019-3340-x.

62. Qingyun Tian; Jingkun Xu; Yinxiu Zuo; Yingying Li; Jialing Zhang; Yaoyi Zhou; Xuemin Duan; Limin Lu; Haiyan Jia; Quan Xu; et al. Three-dimensional PEDOT composite based electrochemical sensor for sensitive detection of chlorophenol. *Journal of Electroanalytical Chemistry* **2019**, *837*, 1-9, 10.1016/j.jelechem.2019.01.055.

63. Mengru Li; Wei Wang; Zhuo Chen; Zhiling Song; Xiliang Luo; Electrochemical determination of paracetamol based on Au@graphene core-shell nanoparticles doped conducting polymer PEDOT nanocomposite. *Sensors and Actuators B: Chemical* **2018**, *260*, 778-785, 10.1016/j.snb.2018.01.093.

64. Li-Na Wu; Jing-Ping Zhong; Muhammad Waqas; Zhe Jiang; You-Jun Fan; Yue Sun; Jia Li; Wei Chen; Controllable synthesis of six corner star-like Cu2O/PEDOT-MWCNT composites and their performance toward electrochemical glucose sensing. *Electrochimica Acta* **2019**, *318*, 837-846, 10.1016/j.electacta.2019.06.124.

65. Davide Bottari; Laura Pigani; Chiara Zanardi; Fabio Terzi; Sanda Victorinne Paţurcă; Sorin Dan Grigorescu; Cristian Matei; Cecilia Lete; Stelian Lupu; Electrochemical Sensing of Caffeic Acid Using Gold Nanoparticles Embedded in Poly(3,4-ethylenedioxythiophene) Layer by Sinusoidal Voltage Procedure. *Chemosensors* **2019**, *7*, 65, 10.3390/chemosensors7040065.

66. Juan José García-Guzmán; David López-Iglesias; Laura Cubillana-Aguilera; Cecilia Lete; Stelian Lupu; José María Palacios-Santander; Dolores Bellido Milla; Assessment of the Polyphenol Indices and Antioxidant Capacity for Beers and Wines Using a Tyrosinase-Based Biosensor Prepared by Sinusoidal Current Method. *Sensors* **2018**, *19*, 66, 10.3390/s19010066.

67. Yi Ge; Ruxangul Jamal; Ruanye Zhang; Wenli Zhang; Zongna Yu; Yinqiang Yan; Yingcheng Liu; Tursun Abdiryim; Electrochemical synthesis of multilayered PEDOT/PEDOT-SH/Au nanocomposites for electrochemical sensing of nitrite.. *Microchimica Acta* **2020**, *187*, 248-10, 10.1007/s00604-020-4211-1.

68. Mahsa Motshakeri; Anthony R. J. Phillips; Jadranka Travas-Sejdic; Paul A. Kilmartin; Electrochemical Study of Gold Microelectrodes Modified with PEDOT to Quantify Uric Acid in Milk Samples. *Electroanalysis* **2020**, *32*, 2101-2111, 10.1002/elan.202060086.

69. Bowen Zhang; Abdelhadi El Jaouhari; Xiangrong Wu; Wei Liu; Jinhua Zhu; Xiuhua Liu; Synthesis and characterization of PEDOT-MC decorated AgNPs for voltammetric detection of rutin in real samples. *Journal of Electroanalytical Chemistry* **2020**, *877*, 114632, 10.1016/j.jelechem.2020.114632.

70. Cecilia Lete; Mariana Marin; Elena Maria Anghel; Loredana Preda; Cristian Matei; Stelian Lupu; Sinusoidal voltage electrodeposition of PEDOT-Prussian blue nanoparticles composite and its application to amperometric sensing of H2O2 in human blood. *Materials Science and Engineering: C* **2019**, *102*, 661-669, 10.1016/j.msec.2019.04.086.

71. Mohamed A. Yassin; Bishnu Kumar Shrestha; Rafiq Ahmad; Sita Shrestha; Chan Hee Park; Cheol Sang Kim; Exfoliated nanosheets of Co3O4 webbed with polyaniline nanofibers: A novel composite electrode material for enzymeless glucose sensing application. *Journal of Industrial and Engineering Chemistry* **2019**, *73*, 106-117, 10.1016/j.jiec.2019.01.011.

72. Elhameh Saeb; Karim Asadpour- Zeynali; ; Facile synthesis of TiO2@PANI@Au nanocomposite as an electrochemical sensor for determination of hydrazine. *Microchemical Journal* **2020**, *160*, 105603, 10.1016/j.microc.2020.105603.

73. Chengqian Duan; Jianbin Zheng; Porous coralloid Polyaniline/SnO2-based enzyme-free sensor for sensitive and selective detection of nitrite. *Colloids and Surfaces A: Physicochemical and Engineering Aspects* **2019**, *567*, 271-277, 10.1016/j.colsurfa.2019.01.063.

74. Omolola E. Fayemi; Abolanle Adekunle; B.E.Kumara Swamy; Eno E. Ebenso; Electrochemical sensor for the detection of dopamine in real samples using polyaniline/NiO, ZnO, and Fe3O4 nanocomposites on glassy carbon electrode. *Journal of Electroanalytical Chemistry* **2018**, *818*, 236-249, 10.1016/j.jelechem.2018.02.027.

75. M.R. Mahmoudian; W.J. Basirun; M. Sookhakian; Pei Meng Woi; E. Zalnezhad; H. Hazarkhani; Y. Alias; Synthesis and characterization of α-Fe2O3/polyaniline nanotube composite as electrochemical sensor for uric acid detection. *Advanced Powder Technology* **2018**, *30*, 384-392, 10.1016/j.apt.2018.11.015.

76. Saraswathi Kailasaa; B. Geeta Rani; M. Sai Bhargava Reddy; N. Jayarambabu; P. Munindra; Sanjeev Sharma; K. Venkateswara Rao; NiO nanoparticles -decorated conductive polyaniline nanosheets for amperometric glucose biosensor. *Materials Chemistry and Physics* **2019**, *242*, 122524, 10.1016/j.matchemphys.2019.122524.

77. Seyed Morteza Naghib; Farahnaz Behzad; Mehdi Rahmanian; Yasser Zare; Kyong Yop Rhee; A highly sensitive biosensor based on methacrylated graphene oxide-grafted polyaniline for ascorbic acid determination. *Nanotechnology Reviews* **2020**, *9*, 760-767, 10.1515/ntrev-2020-0061.

78. Azadeh Tavousi; Elahe Ahmadi; Leila Mohammadi-Behzad; Vahid Riahifar; Fatemeh Maghemi; Sensitive electrochemical sensor using polypyrrole-coated Fe3O4 core-shell nanoparticles/multiwall carbon nanotubes modified graphite electrode for atorvastatin analysis. *Microchemical Journal* **2020**, *158*, 105159, 10.1016/j.microc.2020.105159.

79. Ayyadurai Kannan; Sivaprakasam Radhakrishnan; Fabrication of an electrochemical sensor based on gold nanoparticles functionalized polypyrrole nanotubes for the highly sensitive detection of l-dopa. *Materials Today Communications* **2020**, *25*, 101330, 10.1016/j.mtcomm.2020.101330.

80. Waheed A. Adeosun; Abdullah M. Asiri; Hadi M. Marwani; Mohammed M. Rahman; Enzymeless Electrocatalytic Detection of Uric Acid Using Polydopamine/Polypyrrole Copolymeric film. *ChemistrySelect* **2020**, *5*, 156-164, 10.1002/slct.201903628.

81. Vahid Arabali; Samira Malekmohammadi; Fatemeh Karimi; Surface amplification of pencil graphite electrode using CuO nanoparticle/polypyrrole nanocomposite; a powerful electrochemical strategy for determination of tramadol. *Microchemical Journal* **2020**, *158*, 105179, 10.1016/j.microc.2020.105179.

82. Priscilla Mengarda; Fernando Augusto Lavezzo Dias; João Victor Peixoto; Raul Osiecki; Márcio F. Bergamini; Luiz H. Marcolino-Junior; Determination of lactate levels in biological fluids using a disposable ion-selective potentiometric sensor based on polypyrrole films. *Sensors and Actuators B: Chemical* **2019**, *296*, 126663, 10.1016/j.snb.2019.126663.

83. Junping Ma; Jianbin Zheng; Voltammetric determination of hydrogen peroxide using AuCu nanoparticles attached on polypyrrole-modified 2D metal-organic framework nanosheets. *Microchimica Acta* **2020**, *187*, 1-8, 10.1007/s00604-020-04355-y.

84. Da Ha; Qiyong Sun; Kaiqi Su; Hao Wan; Haibo Li; Ning Xu; Fei Sun; Liujing Zhuang; Ning Hu; Ping Wang; et al. Recent achievements in electronic tongue and bioelectronic tongue as taste sensors. *Sensors and Actuators B: Chemical* **2014**, *207*, 1136-1146, 10.1016/j.snb.2014.09.077.

85. Manel del Valle; Electronic Tongues Employing Electrochemical Sensors. *Electroanalysis* **2010**, *22*, 1539-1555, 10.1002/elan.201000013.

86. Clara Pérez-Ràfols; Núria Serrano; Cristina Ariño; Miquel Esteban; José Manuel Díaz-Cruz; Pérez- Ràfols; Díaz- Cruz; Voltammetric Electronic Tongues in Food Analysis. *Sensors* **2019**, *19*, 4261, 10.3390/s19194261.

87. Dmitry Kirsanov; Daniel S. Correa; Gabriel Gaal; Antonio Riul; Maria L. Braunger; Flavio M. Shimizu; Osvaldo N. Oliveira; Tao Liang; Hao Wan; Ping Wang; et al. Electronic Tongues for Inedible Media. *Sensors* **2019**, *19*, 5113, 10.3390/s19235113.

88. A. Riul; R.R. Malmegrim; F.J. Fonseca; L.H.C. Mattoso; An artificial taste sensor based on conducting polymers. *Biosensors and Bioelectronics* **2003**, *18*, 1365-1369, 10.1016/s0956-5663(03)00069-1.

89. Jr. A. Riul; Jr. D. S. dos Santos; ‡ K. Wohnrath; ‡ R. Di Tommazo; § A. C. P. L. F. Carvalho; ‖ F. J. Fonseca; Jr. O. N. Oliveira; ⊥ And D. M. Taylor; † L. H. C. Mattoso; Artificial Taste Sensor: Efficient Combination of Sensors Made from Langmuir−Blodgett Films of Conducting Polymers and a Ruthenium Complex and Self-Assembled Films of an Azobenzene-Containing Polymer. *Langmuir* **2001**, *18*, 239-245, 10.1021/la011017d.

90. A. Riul; A.M. Gallardo Soto; S.V. Mello; S. Bone; D.M. Taylor; L.H.C. Mattoso; An electronic tongue using polypyrrole and polyaniline. *Synthetic Metals* **2003**, *132*, 109-116, 10.1016/s0379-6779(02)00107-8.

91. A.A Arrieta; C Apetrei; Maria Luz Rodriguez-Mendez; J.A de Saja; Voltammetric sensor array based on conducting polymer-modified electrodes for the discrimination of liquids. *Electrochimica Acta* **2004**, *49*, 4543-4551, 10.1016/j.electacta.2004.05.010.

92. Larisa Lvova; Andrey Legin; Yuri Vlasov; Geun Sig Cha; Hakhyun Nam; Multicomponent analysis of Korean green tea by means of disposable all-solid-state potentiometric electronic tongue microsystem. *Sensors and Actuators B: Chemical* **2003**, *95*, 391-399, 10.1016/s0925-4005(03)00445-3.

93. L. Pigani; G. Vasile Simone; G. Foca; A. Ulrici; F. Masino; Laura Cubillana Aguilera; Rosalba Calvini; R. Seeber; Prediction of parameters related to grape ripening by multivariate calibration of voltammetric signals acquired by an electronic tongue. *Talanta* **2018**, *178*, 178-187, 10.1016/j.talanta.2017.09.027.

94. L. Pigani; A. Culetu; A. Ulrici; G. Foca; M. Vignali; R. Seeber; Pedot modified electrodes in amperometric sensing for analysis of red wine samples. *Food Chemistry* **2011**, *129*, 226-233, 10.1016/j.foodchem.2011.04.046.

95. V. Martina; K. Ionescu; L. Pigani; F. Terzi; A. Ulrici; C. Zanardi; R. Seeber; Development of an electronic tongue based on a PEDOT-modified voltammetric sensor. *Analytical and Bioanalytical Chemistry* **2007**, *387*, 2101-2110, 10.1007/s00216-006-1102-1.

96. Vanessa P. Scagion; Luiza A. Mercante; Karine Y. Sakamoto; Juliano E. Oliveira; Fernando J. Fonseca; Luiz H. C. Mattoso; Marcos D. Ferreira; Daniel S. Correa; An electronic tongue based on conducting electrospun nanofibers for detecting tetracycline in milk samples. *RSC Advances* **2016**, *6*, 103740-103746, 10.1039/c6ra21326j.

97. Yongchao Yu; Pooran C. Joshi; Jayne Wu; Anming Hu; Laser-Induced Carbon-Based Smart Flexible Sensor Array for Multiflavors Detection. *ACS Applied Materials & Interfaces* **2018**, *10*, 34005-34012, 10.1021/acsami.8b12626.

98. C. Garcia-Hernandez; C. Salvo-Comino; F. Martin-Pedrosa; C. Garcia-Cabezon; M.L. Rodriguez-Mendez; Analysis of red wines using an electronic tongue and infrared spectroscopy. Correlations with phenolic content and color parameters. *LWT* **2019**, *118*, 108785, 10.1016/j.lwt.2019.108785.

99. Elisabeta-Irina Geană; Corina Teodora Ciucure; Victoria Artem; Constantin Apetrei; Wine varietal discrimination and classification using a voltammetric sensor array based on modified screen-printed electrodes in conjunction with chemometric analysis. *Microchemical Journal* **2020**, *159*, 105451, 10.1016/j.microc.2020.105451.

100. Vicente Parra; Álvaro A. Arrieta; José-A. Fernández-Escudero; María Luz Rodríguez-Méndez; José Antonio De Saja; Electronic tongue based on chemically modified electrodes and voltammetry for the detection of adulterations in wines. *Sensors and Actuators B: Chemical* **2006**, *118*, 448-453, 10.1016/j.snb.2006.04.043.

101. Irina Mirela Apetrei; C. Apetrei; Application of voltammetric e-tongue for the detection of ammonia and putrescine in beef products. *Sensors and Actuators B: Chemical* **2016**, *234*, 371-379, 10.1016/j.snb.2016.05.005.

102. Álvaro A. Arrieta; Maria Luz Rodriguez-Mendez; José A. de Saja; Carlos A. Blanco; Dieudonné Nimubona; Prediction of bitterness and alcoholic strength in beer using an electronic tongue. *Food Chemistry* **2010**, *123*, 642-646, 10.1016/j.foodchem.2010.05.006.

103. Constantin Apetrei; Novel method based on polypyrrole-modified sensors and emulsions for the evaluation of bitterness in extra virgin olive oils. *Food Research International* **2012**, *48*, 673-680, 10.1016/j.foodres.2012.06.010.

104. Elisabeta-Irina Geană; Victoria Artem; Constantin Apetrei; Discrimination and classification of wines based on polypyrrole modified screen-printed carbon electrodes coupled with multivariate data analysis. *Journal of Food Composition and Analysis* **2020**, *96*, 103704, 10.1016/j.jfca.2020.103704.

105. Juan Manuel Gutiérrez; Laura Moreno-Barón; Maria Isabel Pividori; Salvador Alegret; Manel del Valle; A voltammetric electronic tongue made of modified epoxy-graphite electrodes for the qualitative analysis of wine. *Microchimica Acta* **2010**, *169*, 261-268, 10.1007/s00604-010-0351-z.

106. K. Arshak; E. Moore; G.M. Lyons; J. Harris; Seamus Clifford; A review of gas sensors employed in electronic nose applications. *Sensor Review* **2004**, *24*, 181-198, 10.1108/02602280410525977.

107. Pirsa, S.. Materials Science and Engineering: Concepts, Methodologies, Tools, and Applications; IGI Global: USA, 2017; pp. 150-180.

108. Boris Lakard; Stéphanie Carquigny; Olivier Segut; Tilia Patois; Sophie Lakard; Gas Sensors Based on Electrodeposited Polymers. *Metals* **2015**, *5*, 1371-1386, 10.3390/met5031371.

109. Seon Joo Park; Chul Soon Park; Hyeonseok Yoon; Chemo-Electrical Gas Sensors Based on Conducting Polymer Hybrids. *Polymers* **2017**, *9*, 155, 10.3390/polym9050155.

110. Weiwei Wu; Bin Wang; Meital Segev-Bar; Wei Dou; Fang Niu; Yehu David Horev; Yunfeng Deng; Marian Plotkin; Tan-Phat Huynh; Raneen Jeries; et al. Free-Standing and Eco-Friendly Polyaniline Thin Films for Multifunctional Sensing of Physical and Chemical Stimuli. *Advanced Functional Materials* **2017**, *27*, 1703147, 10.1002/adfm.201703147.

111. Tao Zhang; Haoyuan Qi; Zhongquan Liao; Yehu David Horev; Luis Antonio Panes-Ruiz; Petko St. Petkov; Zhe Zhang; Rishi Shivhare; Panpan Zhang; Kejun Liu; et al. Engineering crystalline quasi-two-dimensional polyaniline thin film with enhanced electrical and chemiresistive sensing performances. *Nature Communications* **2019**, *10*, 1-9, 10.1038/s41467-019-11921-3.

112. Caroline Duc; Mohamed-Lamine Boukhenane; Jean-Luc Wojkiewicz; Nathalie Redon; Hydrogen Sulfide Detection by Sensors Based on Conductive Polymers: A Review. *Frontiers in Materials* **2020**, *7*, 215, 10.3389/fmats.2020.00215.

113. S. Mikhaylov; N. A. Ogurtsov; N. Redon; P. Coddeville; J.-L. Wojkiewicz; A. A. Pud; The PANI-DBSA content and dispersing solvent as influencing parameters in sensing performances of TiO2/PANI-DBSA hybrid nanocomposites to ammonia. *RSC Advances* **2016**, *6*, 82625-82634, 10.1039/c6ra12693f.

114. Kyung Hwa Hong; Kyung Wha Oh; Tae Jin Kang; Polyaniline-nylon 6 composite fabric for ammonia gas sensor. *Journal of Applied Polymer Science* **2004**, *92*, 37-42, 10.1002/app.13633.

115. H Hu; M Trejo; M.E Nicho; J.M Saniger; A García-Valenzuela; Adsorption kinetics of optochemical NH3 gas sensing with semiconductor polyaniline films. *Sensors and Actuators B: Chemical* **2002**, *82*, 14-23, 10.1016/s0925-4005(01)00984-4.

116. Mijuan Xu; Jun Zhang; Shurong Wang; Xianzhi Guo; Huijuan Xia; Yan Wang; Shoumin Zhang; Weiping Huang; Shihua Wu; Gas sensing properties of SnO2 hollow spheres/polythiophene inorganic–organic hybrids. *Sensors and Actuators B: Chemical* **2010**, *146*, 8-13, 10.1016/j.snb.2010.01.053.

117. YaQiong Zhang; Benjamin R. Bunes; Na Wu; Adam Ansari; Saleha Rajabali; Ling Zang; Sensing methamphetamine with chemiresistive sensors based on polythiophene-blended single-walled carbon nanotubes. *Sensors and Actuators B: Chemical* **2018**, *255*, 1814-1818, 10.1016/j.snb.2017.08.201.

118. Dawu Lv; Weigang Chen; Wenfeng Shen; Mingyue Peng; Xuesong Zhang; Runfei Wang; Lei Xu; Wei Xu; Weijie Song; Ruiqin Tan; et al. Enhanced flexible room temperature ammonia sensor based on PEDOT: PSS thin film with FeCl3 additives prepared by inkjet printing. *Sensors and Actuators B: Chemical* **2019**, *298*, 298, 10.1016/j.snb.2019.126890.

119. Jagjeevan Ram; R. G. Singh; Fouran Singh; Vikas Kumar; Vishnu Chauhan; Rashi Gupta; Utkarsh Kumar; B. C. Yadav; Rajesh Kumar; Development of WO3-PEDOT: PSS hybrid nanocomposites based devices for liquefied petroleum gas (LPG) sensor. *Journal of Materials Science: Materials in Electronics* **2019**, *30*, 13593-13603, 10.1007/s10854-019-01728-9.

120. Pengyu Yang; Dawu Lv; Wenfeng Shen; Tieyi Wu; Ye Yang; Yue Zhao; Ruiqin Tan; Weijie Song; Porous flexible polyaniline/polyvinylidene fluoride composite film for trace-level NH3 detection at room temperature. *Materials Letters* **2020**, *271*, 127798, 10.1016/j.matlet.2020.127798.

121. Hongyan Xu; Dianxing Ju; Wenru Li; Haibo Gong; Jun Zhang; Jieqiang Wang; Bingqiang Cao; Low-working-temperature, fast-response-speed NO2 sensor with nanoporous-SnO2/polyaniline double-layered film. *Sensors and Actuators B: Chemical* **2016**, *224*, 654-660, 10.1016/j.snb.2015.10.076.

122. Dongzhi Zhang; Zhenling Wu; Xiaoqi Zong; Flexible and highly sensitive H2S gas sensor based on in-situ polymerized SnO2/rGO/PANI ternary nanocomposite with application in halitosis diagnosis. *Sensors and Actuators B: Chemical* **2019**, *289*, 32-41, 10.1016/j.snb.2019.03.055.

123. S. Kotresh; Y. T. Ravikiran; S. C. Vijayakumari; Sabu Thomas; Interfacial p-n heterojunction of polyaniline-nickel ferrite nanocomposite as room temperature liquefied petroleum gas sensor. *Composite Interfaces* **2016**, *24*, 549-561, 10.1080/09276440.2017.1241523.

124. Xiaohui Tang; Jean-Pierre Raskin; Nadzeya Kryvutsa; Sophie Hermans; Oleksandr Slobodian; Alexei N. Nazarov; Marc Debliquy; An ammonia sensor composed of polypyrrole synthesized on reduced graphene oxide by electropolymerization. *Sensors and Actuators B: Chemical* **2019**, *305*, 127423, 10.1016/j.snb.2019.127423.

125. Sachin Navale; A.T. Mane; M.A. Chougule; R.D. Sakhare; S.R. Nalage; V.B. Patil; Highly selective and sensitive room temperature NO2 gas sensor based on polypyrrole thin films. *Synthetic Metals* **2014**, *189*, 94-99, 10.1016/j.synthmet.2014.01.002.

126. Arpita Adhikari; Punam Tiwary; Dipak Rana; Arijit Halder; Jyotisko Nath; Arijita Basu; Debojyoti Ghoshal; Pradip Kar; Amit Kumar Chakraborty; Dipankar Chattopadhyay; et al. Na-cholate micelle mediated synthesis of polypyrrole nanoribbons for ethanol sensing. *Journal of Environmental Chemical Engineering* **2020**, *8*, 104249, 10.1016/j.jece.2020.104249.

127. Arpita Adhikari; Pradip Kar; Dipak Rana; Sriparna De; Jyotishka Nath; Kingshuk Dutta; Dipankar Chattopadhyay; Synthesis of sodium cholate mediated rod-like polypyrrole-silver nanocomposite for selective sensing of acetone vapor. *Nano-Structures & Nano-Objects* **2020**, *21*, 100419, 10.1016/j.nanoso.2019.100419.

128. Seon Joo Park; Oh Seok Kwon; Jyongsik Jang; A high-performance hydrogen gas sensor using ultrathin polypyrrole-coated CNT nanohybrids. *Chemical Communications* **2013**, *49*, 4673-4675, 10.1039/c3cc41020j.

129. Bhagaban Behera; Rathin Joshi; G K Anil Vishnu; Sanjay Bhalerao; Hardik J Pandya; Electronic nose: a non-invasive technology for breath analysis of diabetes and lung cancer patients. *Journal of Breath Research* **2019**, *13*, 024001, 10.1088/1752-7163/aafc77.

130. Alphus Dan Wilson; Application of Electronic-Nose Technologies and VOC-Biomarkers for the Noninvasive Early Diagnosis of Gastrointestinal Diseases. *Sensors* **2018**, *18*, 2613, 10.3390/s18082613.

131. Baishu Liu; Yan Huang; Kenneth Wl. Kam; Wai-Fung Cheung; Ni Zhao; Bo Zheng; Functionalized graphene-based chemiresistive electronic nose for discrimination of disease-related volatile organic compounds. *Biosensors and Bioelectronics: X* **2019**, *1*, 100016, 10.1016/j.biosx.2019.100016.

132. Nahid Aghili Nategh; Mohammad Jafar Dalvand; Adieh Anvar; Detection of toxic and non-toxic sweet cherries at different degrees of maturity using an electronic nose. *Journal of Food Measurement and Characterization* **2020**, *15*, 1213-1224, 10.1007/s11694-020-00724-6.

133. J.V. Hatfield; P. Neaves; P.J. Hicks; Krishna Persaud; P. Travers; Towards an integrated electronic nose using conducting polymer sensors. *Sensors and Actuators B: Chemical* **1994**, *18*, 221-228, 10.1016/0925-4005(94)87086-1.

134. Rita Stella; Joseph N Barisci; Giorgio Serra; Gordon Wallace; Danilo De Rossi; Characterisation of olive oil by an electronic nose based on conducting polymer sensors. *Sensors and Actuators B: Chemical* **2000**, *63*, 1-9, 10.1016/s0925-4005(99)00510-9.

135. Joseph N. Barisci; Gordon G. Wallace; Michael K. Andrews; Ashton C. Partridge; Paul D. Harris; Conducting polymer sensors for monitoring aromatic hydrocarbons using an electronic nose. *Sensors and Actuators B: Chemical* **2002**, *84*, 252-257, 10.1016/s0925-4005(02)00033-3.

136. Tanushree Sen; Satyendra Mishra; Navinchandra G. Shimpi; Synthesis and sensing applications of polyaniline nanocomposites: a review. *RSC Advances* **2016**, *6*, 42196-42222, 10.1039/c6ra03049a.

137. Sadanand Pandey; Highly sensitive and selective chemiresistor gas/vapor sensors based on polyaniline nanocomposite: A comprehensive review. *Journal of Science: Advanced Materials and Devices* **2016**, *1*, 431-453, 10.1016/j.jsamd.2016.10.005.

138. Haizhou Liu; Yunhui Wu; Song Chen; Shuqi Liu; Pingping Wang; Feng Xue; Lan Liu; A flexible and multifunctional electronic nose using polyaniline/cotton fibrous membrane with a hierarchical structure. *Materials Letters* **2018**, *233*, 324-327, 10.1016/j.matlet.2018.09.046.

139. Lídia Tiggemann; Sandra Cristina Ballen; Cristian Matheus Bocalon; Adriana Marcia Graboski; Alexandra Manzoli; Juliana Steffens; Eunice Valduga; Clarice Steffens; Electronic nose system based on polyaniline films sensor array with different dopants for discrimination of artificial aromas. *Innovative Food Science & Emerging Technologies* **2017**, *43*, 112-116, 10.1016/j.ifset.2017.08.003.

140. Adriana Marcia Graboski; Sandra Cristina Ballen; Elisiane Galvagni; Thiago Lazzari; Alexandra Manzoli; Flávio Makoto Shimizu; Juliana Steffens; Clarice Steffens; Aroma detection using a gas sensor array with different polyaniline films. *Analytical Methods* **2019**, *11*, 654-660, 10.1039/c8ay02389a.

141. Alexandra Manzoli; Clarice Steffens; Rafaella Takehara Paschoalin; Adriana Marcia Graboski; Humberto De Mello Brandão; Bruno Campos de Carvalho; José Luiz Bellini; Paulo Sergio De Paula Herrmann; Volatile compounds monitoring as indicative of female cattle fertile period using electronic nose. *Sensors and Actuators B: Chemical* **2018**, *282*, 609-616, 10.1016/j.snb.2018.11.109.

142. Alexandra Manzoli; Clarice Steffens; Rafaella Takehara Paschoalin; Alessandra A. Correa; William F. Alves; Fabio L. Leite; Paulo S. P. Herrmann; Low-Cost Gas Sensors Produced by the Graphite Line-Patterning Technique Applied to Monitoring Banana Ripeness. *Sensors* **2011**, *11*, 6425-6434, 10.3390/s110606425.

143. Sandra Cristina Ballen; Adriana Marcia Graboski; Alexandra Manzoli; Juliana Steffens; Clarice Steffens; Monitoring Aroma Release in Gummy Candies During The Storage Using Electronic Nose. *Food Analytical Methods* **2019**, *13*, 3-12, 10.1007/s12161-019-01496-6.

144. Paul Le Maout; Jean-Luc Wojkiewicz; Nathalie Redon; Cyril Lahuec; Fabrice Seguin; Laurent Dupont; Sergei Mikhaylov; Yuriy Noskov; Nikolay Ogurtsov; Alexander Pud; et al. Polyaniline nanocomposites based sensor array for breath ammonia analysis. Portable e-nose approach to non-invasive diagnosis of chronic kidney disease. *Sensors and Actuators B: Chemical* **2018**, *274*, 616-626, 10.1016/j.snb.2018.07.178.

145. P. Le Maout; P.S Laquintinie; C. Lahuec; F. Seguin; J-L. Wojkiewicz; N. Redon; L. Dupont; A low cost, handheld E-nose for renal diseases early diagnosis. *2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)* **2018**, *2018*, 2817-2820, 10.1109/embc.2018.8512847.

146. Adriana Marcia Graboski; Claudio A. Zakrzevski; Flavio Makoto Shimizu; Rafaella Takehara Paschoalin; Andrey Coatrini Soares; Juliana Steffens; Natalia Paroul; Clarice Steffens; Electronic Nose Based on Carbon Nanocomposite Sensors for Clove Essential Oil Detection. *ACS Sensors* **2020**, *5*, 1814-1821, 10.1021/acssensors.0c00636.

147. Ambra R. Di Rosa; Anna M. F. Marino; Francesco Leone; Giuseppe G. Corpina; Renato P. Giunta; Vincenzo Chiofalo; Characterization of Sicilian Honeys Pollen Profiles Using a Commercial E-Tongue and Melissopalynological Analysis for Rapid Screening: A Pilot Study. *Sensors* **2018**, *18*, 4065, 10.3390/s18114065.

148. Nikola Major; Ksenija Marković; Marina Krpan; Goran Šarić; Mirjana Hruškar; Nada Vahčić; Rapid honey characterization and botanical classification by an electronic tongue. *Talanta* **2011**, *85*, 569-574, 10.1016/j.talanta.2011.04.025.

149. Xinzhuang Zhang; Yawei Zhang; Qingxiang Meng; Ning Li; Liping Ren; Evaluation of Beef by Electronic Tongue System TS-5000Z: Flavor Assessment, Recognition and Chemical Compositions According to Its Correlation with Flavor. *PLoS ONE* **2015**, *10*, e0137807, 10.1371/journal.pone.0137807.

150. Katharina Woertz; Corinna Tissen; Peter Kleinebudde; Jörg Breitkreutz; A comparative study on two electronic tongues for pharmaceutical formulation development. *Journal of Pharmaceutical and Biomedical Analysis* **2011**, *55*, 272-281, 10.1016/j.jpba.2011.02.002.

151. Miao Liu; Jun Wang; Duo Li; Mingjun Wang; Electronic Tongue Coupled with Physicochemical Analysis for the Recognition of Orange Beverages. *Journal of Food Quality* **2012**, *35*, 429-441, 10.1111/jfq.12004.

152. Miriam Pein; Dmitry Kirsanov; Patrycja Ciosek; Manel del Valle; Irina Yaroshenko; Małgorzata Wesoły; Marcin Zabadaj; Andreu Gonzalez-Calabuig; Wojciech Wróblewski; Andrey Legin; et al. Independent comparison study of six different electronic tongues applied for pharmaceutical analysis. *Journal of Pharmaceutical and Biomedical Analysis* **2015**, *114*, 321-329, 10.1016/j.jpba.2015.05.026.

153. Madara Tirzīte; Māris Bukovskis; Gunta Strazda; Normunds Jurka; Immanuels Taivans; Detection of lung cancer with electronic nose and logistic regression analysis. *Journal of Breath Research* **2018**, *13*, 016006, 10.1088/1752-7163/aae1b8.

154. Or Herman-Saffar; Zvi Boger; Shai Libson; David Lieberman; Raphael Gonen; Yehuda Zeiri; Early non-invasive detection of breast cancer using exhaled breath and urine analysis. *Computers in Biology and Medicine* **2018**, *96*, 227-232, 10.1016/j.compbiomed.2018.04.002.

155. Lorena Díaz De León-Martíne; Maribel Rodríguez-Aguilar; Patricia Gorocica-Rosete; Carlos Alberto Domínguez-Reyes; Verónica Martínez-Bustos; Juan Alberto Tenorio-Torres; Omar Ornelas-Rebolledo; José Alfonso Cruz-Ramos; Berenice Balderas-Segura; Rogelio Flores-Ramírez; et al. Identification of profiles of volatile organic compounds in exhaled breath by means of an electronic nose as a proposal for a screening method for breast cancer: a case-control study. *Journal of Breath Research* **2020**, *14*, 046009, 10.1088/1752-7163/aba83f.

156. Mariana Farraia; João Cavaleiro Rufo; Inês Paciência; Francisca Castro Mendes; Ana Rodolfo; Tiago Azenha Rama; Sílvia Rocha; Luís Delgado; Paul Brinkman; André Moreira; et al. Human volatilome analysis using eNose to assess uncontrolled asthma in a clinical setting. *Allergy* **2020**, *75*, 1630-1639, 10.1111/all.14207.

157. Laura Tenero; Marco Sandri; Michele Piazza; Giulia Paiola; Marco Zaffanello; Giorgio L Piacentini; Electronic nose in discrimination of children with uncontrolled asthma. *Journal of Breath Research* **2020**, *14*, 046003, 10.1088/1752-7163/ab9ab0.

158. Silvano Dragonieri; Vitaliano N Quaranta; Pierluigi Carratu; Teresa Ranieri; Lorenzo Marra; Giuseppina D'Alba; Onofrio Resta; An electronic nose may sniff out amyotrophic lateral sclerosis. *Respiratory Physiology & Neurobiology* **2016**, *232*, 22-25, 10.1016/j.resp.2016.06.005.

159. Xian-Zhe Zheng; Yu-Bin Lan; Jian-Min Zhu; John Westbrook; W. C. Hoffmann; R. E. Lacey; Rapid identification of rice samples using an electronic nose. *Journal of Bionic Engineering* **2009**, *6*, 290-297, 10.1016/s1672-6529(08)60122-5.

160. Changying Li; Gerard W. Krewer; Pingsheng Ji; Harald Scherm; Stanley J. Kays; Gas sensor array for blueberry fruit disease detection and classification. *Postharvest Biology and Technology* **2010**, *55*, 144-149, 10.1016/j.postharvbio.2009.11.004.

161. Federico Autelitano; Felice Giuliani; Analytical assessment of asphalt odor patterns in hot mix asphalt production. *Journal of Cleaner Production* **2018**, *172*, 1212-1223, 10.1016/j.jclepro.2017.10.248.

162. Federico Autelitano; Felice Giuliani; Influence of chemical additives and wax modifiers on odor emissions of road asphalt. *Construction and Building Materials* **2018**, *183*, 485-492, 10.1016/j.conbuildmat.2018.06.168.

163. Brian D. Hosfield; Anthony R. Pecoraro; Nielson T. Baxter; Troy B. Hawkins; Troy A. Markel; The Assessment of Fecal Volatile Organic Compounds in Healthy Infants: Electronic Nose Device Predicts Patient Demographics and Microbial Enterotype. *Journal of Surgical Research* **2020**, *254*, 340-347, 10.1016/j.jss.2020.05.010.

164. Manuela Baietto; Alphus D. Wilson; Daniele Bassi; Francesco Ferrini; Evaluation of Three Electronic Noses for Detecting Incipient Wood Decay. *Sensors* **2010**, *10*, 1062-1092, 10.3390/s100201062.

165. Alphus D. Wilson; Charisse S. Oberle; Daniel F. Oberle; Detection of Off-Flavor in Catfish Using a Conducting Polymer Electronic-Nose Technology. *Sensors* **2013**, *13*, 15968-15984, 10.3390/s131215968.

166. Henike Guilherme Jordan Voss; José Jair Alves Mendes Júnior; Murilo Eduardo Farinelli; Jr. Sergio Luiz Stevan; A Prototype to Detect the Alcohol Content of Beers Based on an Electronic Nose.. *Sensors* **2019**, *19*, 2646, 10.3390/s19112646.
