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Mini Review

Recent Developments in Electrochemical Sensing Platforms for the Detection of Plant Flavonoids

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Flavonoids are a type of bioactive compound that has a strong link to human health. They're also secondary metabolites that have a role in the color, flavor, and texture of plant-based meals. For the quality control and safety evaluation of flavonoids and their associated products, qualitative and quantitative analysis is required. The large number of flavonol glycosides and their complicated structures, on the other hand, make identification and analysis problematic. As a result, it's critical to know how far analytical methods for detecting plant flavonols have progressed in order to research current flavonol molecules. In this study, we examine the most recent research developments in plant flavonol detection methodologies, as well as the operating principles, benefits, and drawbacks of various systems. We describe and discuss the advancement of electrochemical detection of flavonoids in particular. In order to give a theoretical foundation and technological support for the detection and analysis of plant flavonoids, we also address existing issues in the area and provide a view on future research goals.

Keywords: Flavonoids, Electrochemical sensor, Detection, Phytochemistry, Analytical chemistry

1. INTRODUCTION

Flavonols, a kind of flavonoid chemical, are found in abundance in nature. Because of their antioxidant, anti-inflammatory, anti-bacterial, anti-cancer, and other physiological functions, as well as their important therapeutic and preventive effects on aging and chronic diseases like obesity, cardiovascular and cerebrovascular diseases, and Alzheimer's disease [1–4], they are important functional active factors in human diet. At the same time, because of their vital function in the production of color, texture, and flavor in fruits, vegetables, and meals, they have been the focus of study in the field of food science [5–8]. Quality control, safety evaluation, pharmacological effectiveness research,

and new product development all benefit from qualitative and quantitative study of flavonoids in plant raw materials and foods [9,10].

Flavonoids are usually found bound in plants, fruits, and vegetables, despite the fact that they have vital physiological activities. They attach to sugar molecules at the 5-, 3'-, and 4'-sites to create stable glycosides, such as glucose, galactose, rhamnose, pectinose, xylose, and glucuronic acid. It is extremely difficult to separate, extract, and evaluate flavonol glycosides because of their varied isomers, complicated structures, and limits in isolation and detection techniques [11,12]. For the enhancement of current flavonol detection methods and the creation of novel detection methods, it is crucial to grasp the research progress of plant flavonol analysis and detection methods [13,14].

2. DIFFERENT ANALYTICAL METHODS FOR THE DETERMINATION OF PHYTOFLAVONOIDS

2.1 UV spectrophotometer

UV spectrophotometry is a method for determining the absorbance or luminescence intensity of a target substance at a certain wavelength in order to perform qualitative and quantitative analysis. Based on absorption spectra, it is a useful method for studying the target compound's composition, structure, and interactions with other chemicals [15–18]. When compared to other detection methods, the UV spectrophotometer method has the advantages of being simple to use, having minimal instrument and detection costs, and having a short detection time. It is now frequently utilized in the pharmaceutical industry to detect flavonoids [19–22]. Hamasalih et al. [23] effectively developed a UV spectrophotometric technique for the simultaneous detection of quercetin and heptaerythrolactone in Zingiber officinale. The approach is quick, easy, and repeatable, and it may be used to determine quercetin concentration in Chinese herbal remedies as an alternative to traditional methods. Using a UV spectrophotometer, Chaudhari et al. [24] devised a technique for determining rutin and quercetin in vesicular formulations simultaneously. The approach is simple, quick, sensitive, and accurate, and it may be used to analyze rutin and quercetin quantitatively at detection wavelengths of 257 nm and 372 nm, respectively. Chaudhari et al. [25] developed a technique for detecting quercetin and tramadol hydrochloride in vesicular formulations using UV spectrophotometry the following year. The approach is sensitive and specific, with efficient detection of quercetin at 372 nm, in addition to being simple and quick to determine the sample. Chen et al. [26] devised a UV spectrophotometric technique for determining quercetin in APIs quickly. The technique may be used to determine quercetin content with great accuracy and linearity at 374 nm, with a recovery rate of 100.88 percent. The UV spectrophotometer technique, as a conventional method for detecting plant flavonoids, offers the benefits of ease of use, cheap detection cost, and quick detection time. The sensitivity of the target compounds to interference from the matrix solution, other components in the detection system, and the cleanliness of the absorption cell during the detection process restrict its applicability in the detection of plant flavonols [27–32]. Currently, natural flavonol detection is generally used to identify traditional Chinese herbal medicines or pharmaceutical preparations, and the number of target chemicals that may be

detected is restricted. How to successfully eliminate the interference of complex matrices and other components will be a critical topic for future UV spectrophotometric systems to tackle in the future.

2.2 High performance liquidchromatography, HPLC

High-pressure liquid chromatography (HPLC) is a technique for separating chemicals using variations in partition coefficients, affinity, and adsorption capacity between the stationary and mobile phases. It's a brand-new detection method based on classic liquid chromatography that's also the most widely used for plant flavonoid component identification. It has low detection limits, high sensitivity, high analytical efficiency, and a wide analytical range when compared to the UV spectrophotometer technique [33,34]. In order to perform qualitative and quantitative analysis of target molecules, HPLC, being a very effective separation technology, must eventually be paired with a variety of detection devices [35]. UV detection, fluorescence detection, and diode array detection are some of the current detection techniques available. HPLC-UV and HPLC-DAD tests, for example, have proven to be one of the most successful techniques for the qualitative and quantitative study of flavonoid molecules such as flavonols from plants and food products [36–38].

In the traditional Chinese herb Senecio cannabifolius, Niu et al. [39] devised a technique for simultaneous analysis of nine flavonols. By using reversed-phase high-performance liquid chromatography with diode array detection (RP- HPLC- DAD). The separation column in this approach is a C18 column, and the mobile phase is aqueous acetonitrile. Gradient elution is an excellent method for separating and identifying flavonols in a material. The minimal detection limits for the nine flavonols varied from 0.028 to 0.085 g/mL, while the recovery rates ranged from 90.6 to 102.5 percent. The technique is sensitive and reliable, and it may be used to determine flavonols in Chinese herbal medicine. Maimaiti et al. [40] used high-performance liquid chromatography and dipole array detection to develop a technique for quantifying flavonols such as quercetin and kaempferol in several apricot cultivars from Xinjiang (HPLC-PAD). The technique employs a mobile phase of methanol-phosphoric acid solution (55:45, V/V) to separate quercetin and kaempferol in samples at 360 nm. It's an appropriate assay for quality control and assessment of Batan apricots because of its high recovery and linear range.

The HPLC - DAD technique was employed by Benmeziane et al. [41] to identify flavonol in the skins of three distinct fresh red grape varietals, and four flavonol glycosides, predominantly quercetin glycosides, were found. Ma et al. [42] devised an HPLC technique for determining flavonol chemicals in Ginkgo biloba leaves quickly and accurately. Within 13 minutes, flavonol glycosides (quercetin, kaempferol, and isorhamnetin) and glycosides (rutin) in Ginkgo biloba extract may be determined simultaneously. The types and contents of flavonol compounds were found to be an important basis for determining whether Ginkgo biloba extracts and related products were adulterated, providing a practical method for the identification of Ginkgo biloba products, based on the analysis of 13 Ginkgo biloba samples, 15 standard extracts, and 10 Ginkgo biloba products. HPLC has the advantages of a wide detection range, low detection limit, and high sensitivity when compared to UV spectrophotometer methods, but it is still limited in the detection of plant flavonols due to its high detection equipment cost, long detection time for individual samples, complicated operation steps, high sample pretreatment

requirements, and high reagent consumption. Problems including the difficulty to adequately isolate and quantify low-level chemicals in complex systems have become significant roadblocks to their widespread use in plant flavonol detection.

2.3 Liquid chromatography ─mass spectrometry, LC-MS

Because of their low cost and ease of operation, liquid chromatography with UV detection or liquid chromatography with diode array detection are commonly used to determine plant and food flavonoids. Due to the great diversity and complicated structure of flavonol glycosides in nature, however, it is challenging to obtain effective separation and precise quantification of some flavonol glycosides with low concentration using high performance liquid chromatography and common detectors. For the qualitative and quantitative analysis of flavonol molecules in nature, liquid chromatography-mass spectrometry (LC-MS) has become one of the most used approaches [43–45]. It can detect the relative molecular mass and fragment ions of the target compounds while gathering UV spectrum information, and perform a thorough investigation of the substance's structure [46,47]. It has great sensitivity and anti-interference capabilities at the same time. LC-UV-ESI-MS /MS was used by Yaque et al. [48] to identify flavonol chemicals in Talipariti elatum flowers, and quercetin glycosides were discovered to be major components of ginkgo blossoms. Wu et al. [49] devised an HPLC-UV/ESI-MS technique for determining 24 polyphenolic chemicals in green tea, black tea, and oolong tea at the same time, including flavonols. The approach was utilized to simultaneously identify the target compounds using chromatographic retention time and mass spectrometric data, as well as to distinguish the phenolic content of various species. In the absence of target compound standards, mass spectrometric data was shown to be a useful supplement in identifying the target compounds. This approach has been shown to be effective in detecting phenolic chemicals such as flavonols in green, black, and oolong teas. Using high-performance liquid chromatography and tandem time-of-flight mass spectrometry, Wu et al. [50] discovered 15 flavonol glycosides in four Camellia sinensis cultivars (HPLC-TOF-MS). The flavonol glycosides were measured using multiple reaction monitoring (MRM) and high performance liquid chromatography-triple quadrupole mass spectrometry. The detection and quantification limitations of this approach revealed that it is more sensitive than HPLC and has superior data repeatability. Tea bushes have flavonols in the form of mono-, di-, and tri-glycosides, which are largely found in the young leaves. In each tea tree species studied, myricetin-3- O- galactoside had the greatest concentration. Souza et al. [51] employed isopropylidene-modified flavonol glucoside and galactoside isomers as well as liquid chromatography tandem multistage mass spectrometry to determine the flavonol glucoside and galactoside isomers (LC-MSn). They discovered that using this strategy, they were able to overcome the challenge of identifying flavonol glucoside isomers that were difficult to identify. In addition, polysaccharides in complicated matrices can be identified using this technology.

As a result, after the standard HPLC technique, LC-MS has emerged as an emerging detection method that can efficiently extract the relative molecular masses and fragment ions of compounds as well as give a full study of their structure. For the identification of some complex chemicals and low-level molecules, LC-MS can be a useful addition to traditional HPLC tests. It is now employed to detect

flavonols and glycosides in plants, and it is particularly useful for identifying flavonol glycosides. By appropriately modifying flavonol glycoside isomers, LC-MS may be applied in the field of flavonol glycoside isomer identification as well. The expensive cost of detection and the instrument's poor popularity, however, are also downsides of this technology. Its applicability is currently restricted due to its inability to efficiently detect isomers of target molecules from complicated mixtures. Although MS can successfully identify the molecular structure of chemicals, it requires high sample purity and content, and sample purification is typically time-consuming and difficult, therefore identifying flavonols in nature remains a big technological issue.

2.4 Ultra performance liquidchromatography, UPLC

UPLC (ultra-high-performance liquid chromatography) is a novel detection method based on the HPLC technology. It offers the advantages of speed, high efficiency, high resolution, and superior sensitivity when compared to the HPLC technique. Its usage in the identification of flavonol glycosides and glycosides that are more difficult to detect has gotten increased attention in recent years [52–55]. Shim et al. [56] devised a technique for determining flavonol glycosides such as prunetin, quercetin, kaempferol, and isorhamnetin in foods using ultra performance liquid chromatography-photodiode array detection (UPLC-PDA). The flavonol molecules popcornone, quercetin, kaempferol, and isorhamnetin were separated using a reversed-phase C18 column. The detection period was just 13 minutes to guarantee good peak separation, considerably improving the speed, sensitivity, and resolution of flavonol glycoside detection in food. Zhang et al. [57] devised a technique for determining flavonols in red onion using ultra performance liquid chromatography with photodiode array detection and tandem quadrupole mass spectrometry (UPLC -PAD-MS/MS). Not only can the method identify 13 flavonols and their glycosides in red onion at the same time, but it can also distinguish the distribution and quantity of flavonols in different regions of the onion, making it a simple, quick, and accurate approach for determining flavonols in onion. Kim and Shim [58] devised a technique for determining 12 flavonol glycosides in buckwheat, black tea, and wild parsley at the same time. The flavonol glycosides were separated using the UPLC technique, and the target compounds were detected using the PDA method. At a detection wavelength of 350 nm, the recoveries of the 12 flavonol glycosides ranged from 85.44 percent to 108.79 percent. The detection limits (LOD) and quantification limits (LOQ) were 0.32 mg/kg and 0.97 mg/kg, respectively. Using a UPLC-PD-MS /MS) coupling technology, Wang et al. [59] identified flavonol glycosides in tea. Green and black tea contain a total of 15 flavonol glycosides, including 6 quercetin glycosides, 3 populone glycosides, and 6 kaempferol glycosides, according to the researchers. By using tandem quadrupole mass spectrometry to quantify flavonol glycosides in the samples, it was discovered that there was a significant variation in the amount and distribution of flavonol glycosides in green tea and black tea (p 0.05). Green tea has approximately 1.7 times the amount of flavonol glycosides as black tea. For the first time, Jiang et al. [60] employed the UPLC technique to identify flavonol glycosides in green tea, oolong tea, and black tea. Electrospray tandem mass spectrometry was used to identify 18 flavonol glycosides. Flavonol glycosides were found in amounts ranging from 2.32 to 5.67 g/kg. The overall quantity of flavonol glycosides in green tea, oolong tea, and

black tea did not differ substantially in a comparative examination of flavonol glycosides in different tea species, but the kinds and amounts of monomeric flavonol glycosides in different tea species differed. Green tea contains kaempferol glycosides, oolong tea has quercetin and yangmei ketone glycosides, and black tea contains quercetin glycosides.

With its greater pressure and shorter column, the UPLC produces reduced peak dispersion and greatly increased detection speed, resolution, and sensitivity. It offers the following benefits over the standard HPLC method: easy operation, high accuracy, fast detection time, high detection efficiency and sensitivity, and strong target chemical separation ability [61–63]. UPLC has been used to identify flavonol glycosides and glycosides of numerous foods and plants, such as tea, onion, and ginkgo, as well as to conduct qualitative and quantitative investigations on them.

2.5 Capillary electrophoresis, CE

CE is a liquid-phase separation technology that employs capillary tubes as the separation platform and a high-voltage DC electric field as the driving force to separate target compounds based on their various trickling and partitioning characteristics in a given environment [62,64–66]. CE provides the following benefits over classic chromatographic detection methods: high column efficiency, good resolution, high automation, wide application, quick analysis time, easy pre-treatment, low reagent and sample consumption, and economic and environmental protection [67–69]. It is currently frequently utilized for the analysis of flavonols in plants and foods as a viable alternative to the HPLC approach. By using high-performance CE, Zhou et al. [70] discovered flavonol components in buckwheat from various production sites. They discovered that under the right electrophoretic conditions, flavonol molecules like rutin, quercetin, and kaempferol could be easily separated. Gatea et al. [71] devised a CE approach that took only 27 minutes to determine 20 polyphenolic chemicals in propolis and plant extracts. Flavonol substances such as rutin, quercetin, kaempferol, and galangin are well separated with this approach. Under optimal electrophoretic conditions, the minimal limits of detection and quantification for each chemical varied from 0.02 to 1.75 g/mL and 0.07 to 5.77 g/mL, respectively. Wang et al. [72] used capillary electrophoresis and amperometric detection to create a technique for the isolation and identification of eight flavonoids in traditional Chinese herbal medicine. Within 33 minutes, this approach can separate flavonols including rutin, quercetin, quercetin, kaempferol, and apigenin, all of which have low detection limits. The approach was utilized to successfully identify rutin, quercetin, quercetin, and kaempferol in traditional Chinese herbal remedies such as sea buckthorn, forsythia, and cypress leaf, with recoveries ranging from 84.7 percent to 113 percent, respectively. Memon et al. [73] used CE with a photodiode array detector to develop a technique for rapidly separating flavonoid components in fruits (CE-PAD). Flavonols like rutin and quercetin may be separated effectively using this approach. The procedure is reliable and repeatable, and it may be used to determine flavonols in fruits and fruit juices.

As a result, CE is currently being used in the detection of flavonol molecules in a wide range of plants and foods. It's a potential alternative to HPLC for determining bioactive compounds in plants and foods, such as flavonols. Due to its different separation mechanisms, CE has a variety of separation

modes such as capillary zone electrophoresis, micellar electrokinetic capillary chromatography, capillary gel electrophoresis, capillary isoelectric focusing, capillary isotropic electrophoresis, and various detection methods such as laser induced fluorescence detection, ultraviolet detection, mass spectrometry, and amperometric detection. The current application model for detecting plant flavonols is still somewhat limited, and it will need to be expanded in future investigations.

3. ELECTROCHEMICAL ANALYSIS IN THE DETERMINATION OF FLAVONOID

The redox response of chemicals in solution on the surface of a working electrode is the basis for electrochemical analysis. Tests including cyclic voltammetry, differential pulse voltammetry, and square wave voltammetry are used to investigate the electrochemical behavior of compounds [74–79]. Certain physical properties of the cell, such as potential, current, and so on, can be used to determine the substance's content. Flavonoids are a type of natural antioxidant with antioxidant and anti-free radical physiological action that can help to slow down the aging process and prevent illnesses linked to flavonoids' redox behavior. Because electrochemical methods are based on redox processes, many researchers choose electrochemical methods for the detection and study of flavonoids [80–82].

The electrochemical reaction of the material to be measured on the electrode surface is prevented by the electrical characteristics of the general working electrode surface, which are so homogenous. The electrochemical reaction rate is slowed, and efficient electron transport between the sample and the electrode is prevented [83,84]. Since their invention, modified electrodes have been a more active field of electrochemical detection study because they may selectively adjust the electrode's performance based on the research demands. To fix materials or substances with outstanding qualities at the electrode interface, electrode modification can be made using adsorption, covalent bonding, electrochemical technique, coating method, and other preparation methods. Modified electrodes, such as carbon paste modified electrodes, can also be made by grinding and combining the modifier with the electrode material. When it comes to detecting target molecules, the modified electrodes offer superior selectivity and sensitivity than the bare electrodes.

3.1 Carbon nanomaterials modified electrodes

Electrochemists are becoming interested in nanomaterials modified electrodes. Nanomaterials are materials with dimensions ranging from 0.1 to 100 nanometers, or materials made out of fundamental units [87]. Nanomaterials exhibit special physical and chemical features, such as the tiny size effect, quantum size effect, surface effect, macroscopic quantum tunneling effect, and so on. They have a wide range of applications and play an essential role in electrochemical analysis [88,89].

Since its discovery, carbon nanomaterials have been at the forefront of nanotechnology. Fullerenes (C60), carbon nanotubes (CNTs), and graphene are the most common carbon nanomaterials (GR). The use of carbon nanoparticles in electrochemical sensors has a lot of promise for study and application [90,91]. Graphene is a honeycomb-shaped two-dimensional carbon nanomaterial. Carbon

nanotubes are single-walled carbon nanotubes (SWCNTs), multi-walled carbon nanotubes (MWCNTs), and double-walled carbon nanotubes that are composed of graphene layers wrapped into nanometer-sized sheets (DWCNTs). Graphene and carbon nanotubes are frequently employed as modified electrode materials for electrochemical detection of flavonoids because of their good features such as small size, large surface area, quick electron transfer, and high sensitivity [92]. For electrochemical detection of quercetin, Fu et al. [93] employed a graphene/Nafion membrane modified glassy carbon electrode. Wang et al. [94] developed a single-walled carbon nanotube-modified glassy carbon electrode with strong electrocatalytic activity for naringenin detection, and the known electrochemical technique for naringenin detection was applied to determine naringenin in actual samples.

3.2 Carbon nanocomposite modified electrodes

Carbon nanotubes and graphene are used as the carbon basic materials in most electrochemically modified electrodes, which are then combined with other materials. When changed on the electrode surface, these composites can work together to create superior electrochemical catalytic effects. Carbon nanoparticles can be made up of two or even three distinct components. Many materials are mixed with carbon nanoparticles, and the resulting carbon-based nanocomposites are commonly utilized in electrochemical biosensors for the detection and analysis of flavonoids. Chen et al. [95] used a combination of carbon nanotubes and graphene to create composite modified electrodes for detecting quercetin in buckwheat tea under optimal circumstances. To detect chrysin, Li et al. [96] added single-walled carbon nanotubes (SWCNTs) and zirconium dioxide (ZrO_2) nanoparticles to glassy carbon electrodes in the presence of the surfactant sodium dodecyl sulfate (SDS). Miao et al. [97] examined the electrochemical detection of rutin using a graphene-modified glassy carbon electrode functionalized with polydiallyldimethylammonium chloride. Yang Ran and colleagues developed a polydiallyldimethylammonium chloride functionalized graphene cadmium telluride quantum dots nanocomposite modified glassy carbon electrode for sensitive geranium electrochemical detection.

3.3 Application of metal nanoparticles in modified electrodes

Nanomaterials also contain metal nanoparticles such as gold (Au), silver (Ag), platinum (Pt), copper (Cu), palladium (Pd), and other metal nanoparticles. Metal nanoparticles have their own electrochemical characteristics in addition to the features of nanomaterials. Using PtNPs, AuNPs, and biomass-derived porous carbon prepared as composite modified ionic liquid carbon paste electrode, Liu et al. [98] studied the electrochemical behavior of quercetin and sensitively detected the content of quercetin in Ginkgo biloba leaves, which has a broad application in the detection of flavonoids.

Metal nanoparticles doped in carbon nanomaterials, which are utilized to make nanocomposite modified chemical electrodes, are extensively employed and can have a synergistic impact on the electrodes' detection sensitivity and selectivity for analytes. The active sites of gold nanoparticles are quickly filled by protective agents, according to Hu et al. [99], limiting their catalytic activity. For the effective detection of flavonoids rutin and baicalin, they employed an electroless deposition approach to

create multi-walled carbon nanotubes filled with gold nanoparticle material modified glassy carbon electrode.

3.4 Ionic liquid modified electrodes

Ionic liquids are liquids that include both anions and cations. Many different types of ionic liquids may be made depending on the makeup of anions and cations. Because of their high electrical conductivity, wide potential window, non-volatility, and stability, ionic liquids are commonly utilized in electrochemistry. To make a composite modified electrode, the ionic liquid can be applied dropwise to the electrode surface or combined with other carbon materials. Shang et al. [100]made a modified carbon paste electrode with N-butylpyridinium trifluoromethanesulfonate to study the electrochemical behavior of lignocaine on it. They discovered that a modified carbon paste electrode with N-butylpyridinium trifluoromethanesulfonate had strong electrocatalytic activity for lignocaine and went on to investigate the electrochemical reaction mechanism of lignocaine on the modified electrode.

3.5 Molecularly imprinted polymers based electrochemical sensors

MIPs (molecularly imprinted polymers) are polymers made utilizing molecular imprinting processes that are extremely selective and specific for target molecule identification. Molecular Imprinting Technology (MIT) is a new technique that involves covalent or non-covalently connecting a target molecule to a functional monomer, then removing the target molecule from the polymer in some fashion to produce a polymer containing steric holes. This cavity, with its molecular structure and functional group arrangement, has the capacity to bind and detect the target molecule precisely. The interaction of lock and key, enzyme and substrate, and antigen and antibody may be graphically illustrated as the connection of specific identification of target molecules by MIP. Structure stability, extended shelf life, exact identification of target compounds, and good selectivity are all characteristics of MIP. Because of their inexpensive cost, quick reaction time, and excellent sensitivity, MIP electrochemical sensors have been used in the analytical detection of flavonoids.

Xie et al. [101] used a drop coating approach to create a graphene modified gold electrode, and then used cyclic voltammetry to create a rutin MIP film on the surface of the modified gold electrode using o-aminophenol as a functional monomer and rutin as a template molecule. The electrochemical behavior of rutin was studied using this MIP built rutin molecularly imprinted electrochemical sensor, which was then used to the detection of rutin concentration in black tea. Niu et al. [102] constructed molecular MIP sensors for the measurement of goldfinch isoflavones using carboxylated multi-walled carbon nanotubes and molecularly imprinted polymer modified glassy carbon electrodes.

4. APPLICATION OF DIFFERENT MODIFIED ELECTRODES IN THE DETERMINATION OF FLAVONOIDS

Many academics have published on studies on the identification of flavonoids using electrochemical analysis in recent years. The sensitivity and selectivity of chemically modified

electrodes have been greatly improved as a result of the rapid development of materials such as carbon nanomaterials, metal nanoparticles, metal oxides, ionic liquids, and MIPs, which has greatly accelerated the development of electrochemical analysis and brought exuberance to the application of electrochemical analysis methods. The advancement of electrochemical analysis has been substantially accelerated, giving electrochemical analysis methodologies a new lease of life. In recent years, various experts have published study papers on electrochemical techniques for determining flavonoids content.

Table 1. Recent reported electrochemical sensor for detection of flavonoids

Flavonoids	Electrochemical sensor	Linear of detection	LOD	Reference
Catechol	Al/SiO_2/CPE	0.5-50 μM	100 nM	[103]
Catechol	CNT/carbon paper	1-100 μM	290 nM	[104]
Catechol	Gr/GNRs/AgNPs/PPO	2-2300 μM	-	[105]
Catechol	Banana tissue/CPE	1.4-15.7 mg/L	100 ng/L	[106]
Catechol	Biomimetic oxidase/GO	50-1600 μM	90 nM	[107]
Catechin	fMWCNT/YHCF/GCE	5-200 μM	280 nM	[108]
Catechin	N-doped carbon/GCE	1-30 μM	88 nM	[109]
Catechin	Cu@g-C_3N_4	100-900 μM	15.12 μM	[110]
Caffeic acid	Pt-PEDOT/rGO	0.005-0.5 μM	2 nM	[111]
Caffeic acid	MWCNT/SPEs	2–50 μM	200 nM	[112]
Caffeine	PLCY/N-CNT/GCE	0.10-70.0 μM	0.033 μM	[113]
Caffeine	Cork-graphite electrode	5-1000 μM	2.94 μM	[114]
Caffeine	GrRGC	5–1000 μM	6.1 μM	[115]
Epigallocatechin-3-gallate	Gallate-graphite paste	5–14 μM	70 nM	[116]
Epigallocatechin-3-gallate	MIP	0.15–0.75 μM	-	[117]

5. CONCLUSION

Flavonoids are becoming increasingly vital in people's health, thus it's important to develop effective and quick ways for detecting them. Flavonoids have been detected and analyzed using spectroscopy, chromatography, and capillary electrophoresis. Electrochemical analysis may be used to explore the antioxidant mechanism of natural flavonoids, the kinetic processes of flavonoids on electrodes, and the interactions between flavonoids and biomolecules such as proteins, in addition to identifying the kinds and concentrations of flavonoids. Electrochemical sensors have increasingly distinct benefits over other analytical methods, and the implementation of qualitative and quantitative flavonoids analysis also plays a vital role in the quality control and safety evaluation of the items in question.

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