Biosensor Technology for Pesticides—A review

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Abstract: In recent years, numerous enzymatic electrochemical biosensors have been developed as convenient and time-saving analytical techniques for the detection of various analytes for environmental and food analysis. Using integrated enzymatic biosensors, numerous biosensing techniques have been developed recently for the detection of pesticides. Improvements have been made in several enzyme immobilization techniques, electrochemical signal converters, and measuring procedures based on enzymatic biosensors. Since 2005, developments in the design and construction of biosensors for pesticide detection have been reviewed in this review. The utilization of various biosensors developed in food and environmental safety, as well as the state-of-the-art selection of receptors, quick screening procedures, and transduction techniques, are highlighted. The benefits and downsides of different methods are then enumerated. Lastly, difficulties, tactics, and perspectives on further developing pesticide biosensors are also discussed. In recent years, numerous enzymatic electrochemical biosensors have been developed as convenient and time-saving analytical techniques for the detection of various analytes for environmental and food analysis. Using integrated enzymatic biosensors, numerous biosensing techniques have been developed recently for the detection of pesticides. Improvements have been made in several enzyme immobilization techniques, electrochemical signal converters, and measuring procedures based on enzymatic biosensors. Since 2005, developments in the design and construction of biosensors for pesticide detection have been reviewed in this review. The utilization of various biosensors developed in food and environmental safety, as well as the state-of-the-art selection of receptors, quick screening procedures, and transduction techniques, are highlighted. The benefits and downsides of different methods are then enumerated. Lastly, difficulties, tactics, and perspectives on further developing pesticide biosensors are also discussed.

Keywords: Enzyme biosensor Pesticides Food Environmental Electrochemical biosensor Pesticide residue detection. Optical biosensor. Immunosensor. Instrumental analytical approach.

INTRODUCTION

By integrating the signal trigger, signal converter, signal processor, and peripheral function expansion module, these biosensor-based pesticide residue detection instruments enable fast detection of pesticide residues in food with automated data processing, display, and storage. The direction of biosensor development for pesticide residue detection that is appropriate for industrial or commercial use would be biosensor-based instrumentation and devices. Chemical pesticides Pesticides are mostly utilized in agricultural settings to boost crop output because of their economic outcomes. Different types of pesticides have been developed to linger in the environment longer after being applied .[44,45]

Precise and timely pesticide analysis is crucial because of the many pesticides that are regularly used and their harmful effects on human health. Traditional pesticide detection techniques, like chromatographic techniques (HPLC, GC, etc.), possess a multitude of disadvantages, such as being time-consuming, labor-intensive, having stumpy sensitivity and efficiency, requiring expensive equipment and highly skilled workers, and many more. Based on a review of the literature conducted with Thomson Reuters Web of Science, over 1,400 journal articles, book chapters, and patents related to pesticide sensors have been published since 1989. Over the past 20 years, the total number of publications has grown dramatically, with 40–50% of those papers based on enzyme inhibition techniques. Pesticide biosensors can generally be divided into two main groups: biosensors based on enzymes.[6,7] As a result, the contamination caused by organophosphorus insecticides has drawn increased attention from researchers and emerged as a major issue. To maintain food quality and shield people from potentially harmful hazards, it is necessary to continuously analyze and monitor the residue of OP pesticides in food and water on-site and in real time. As a type of signal trigger, biosensors were unable to

immediately obtain the results of pesticide residue detection; instead, the acquisition signal had to be converted into detection values through signal access and collection. Rapid pesticide residue detection devices have emerged as a result of related technologies developing and biosensor technology and application technology coming together.[4,27]

Pesticides—Introduction and life threat

Pesticides are categorized as organochlorine, organophosphate, carbamate, synthetic pyrethroides, inorganic pesticides, etc. based on their chemical composition. [29, 30] In addition to several other compounds, pesticides can also be categorized according to the target they are used against. For example, insecticides are used to control insect pests; nematocides are used to control nematodes; fungicides are used to control fungus; and weedicides are used to control weed pests. [31, 32]

The irreversible use of pesticides raises serious concerns since it exposes living things to a variety of toxicological effects through both direct and indirect contact with the chemicals and their residues. Pesticides present in the environment can be exposed to humans through a variety of pathways, including the skin, respiratory system, ingestion, and others. Numerous pieces of data suggest that the pesticide has unfavorable impacts on the ecosystem, which puts all kinds of life forms in danger. [33,34]

Types:

Enzyme-inhibition-based biosensor

The relationship between pesticide toxicity and decreased enzyme activity serves as the foundation for the general concept of the biosensors that have been created. Consequently, a quantitative assessment of the enzyme activity prior to and following exposure to a target analyte is necessary for the development of these biosensing systems. [8,9,10]. This amperometric enzymatic biosensor measures the substrate-enzyme interaction product, thiocholine. [1]. In another work, Liang et al. [2] developed an electrochemiluminescence-based biosensor for the determination of organophosphorus pesticides. The biosensor, whose principle is associated with the inhibition of AChE, was also successfully applied to real vegetable samples. [3]

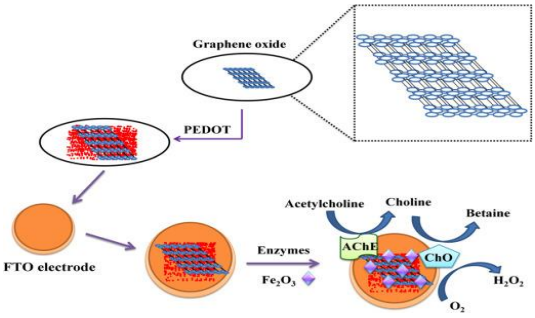

Fig.1Enzyme-inhibition-based biosensor [48]

Instruments of Electrochemical Biosensors

Because of the high inherent sensitivity of electrochemical detection as well as the potential for portability and downsizing, electrochemical biosensors have emerged in recent years as the most viable substitute for pesticide detection. The most traditional and widely utilized techniques in biosensors. [12] The rapid and sensitive detection of redox-active target analytes is made possible by electrochemical detection techniques, which do not require complicated sample pretreatment. [13,14]

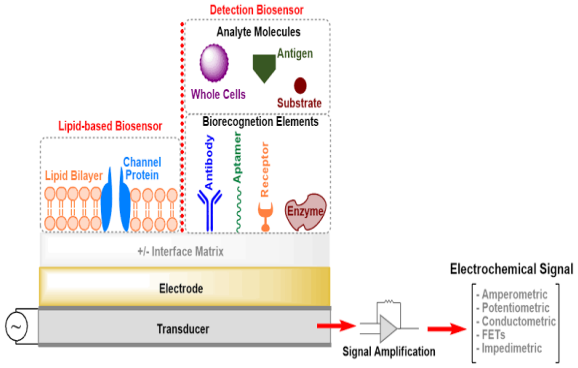

Fig. 2 Electrochemical Biosensors[53]

Optical immunosensors:

Optical techniques such as absorbance, fluorescence, or surface plasmon resonance can be used to assess the observable signal change that occurs from the specific high sensitivity, selectivity, and easy miniaturization for usage in portable devices. [14] However, the process of immobilizing enzymes on an electrode surface is sometimes laborious and time-consuming. Optical biosensors have been employed as a substitute to get around these issues since they are dependable, simple to utilize, quick, and highly sensitive.[14]

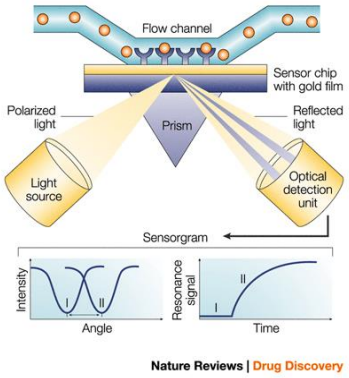

Fig. 3 Optical immunosensors: [47]

Catalytic Biosensors:

The activity of the enzyme organophosphorus hydrolase (OPH) is the basis for another strategy for the creation of enzyme biosensors for pesticides. One of the common bacterial enzymes called phosphotriesterase is OPH, and pesticides function as the enzyme's substrate rather than an inhibitor. Organophosphorus insecticides, including parathion, methyl parathion, and paraoxon, hydrolyze when exposed to OPH. Because many other compounds, including carbamate and heavy metals, can inhibit these enzymes, inhibition-based biosensors are sluggish, indirect, and have limited selectivity, despite being extremely sensitive (able to detect up to 1×10−10 M).[42, 43]

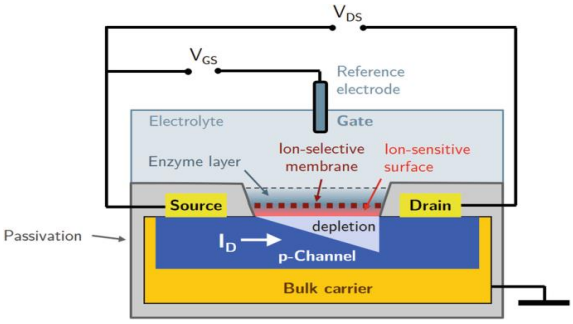

Fig .4 Catalytic Biosensors [49]

Ellipsometric biosensors:

An ellipsometric biosensor monitors changes in the polarization of light as it reflects off of a surface. Using this platform, the binding patterns of many influenza A virus strains to a panel of glycans of various structures were determined. The apparent equilibrium dissociation values, or avidity constants, 10–100 pM, were used to define the features of viral receptor profiles [15]. Using microarray biosensors based on total internal reflection imaging ellipsometry, the estimated detection limit of the serum tumor biomarker CA19-9 was 18.2 units · ml−1, which is less than the cut-off value for a normal level [16, 17]

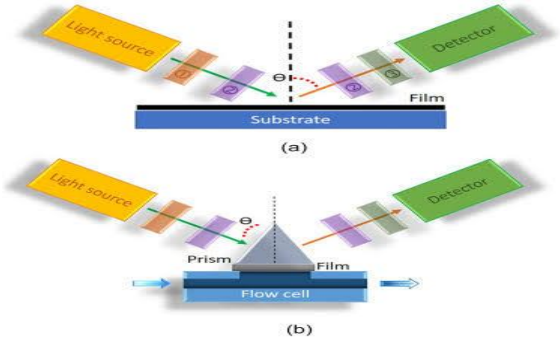

Fig.5 Ellipsometric biosensors [50]

Immune biosensors.

Since immunological methods are the most effective for identifying any particular material, we focused on developing a variety of optical, thermometric, and electrochemical biosensors. Figure shows the optical device's scheme, which uses the sNPS for photoresistance. registration of the signal at the point where the particular immune complex forms. provides a thorough explanation of the contacts and layers that were employed in the immunological biosensor based on the sNPS. The particular Ab was applied to the photoresistor surface between the contacts at the start of the measurement in a volume of 1µl. This solution was then allowed to evaporate in the air or at room temperature.[21]

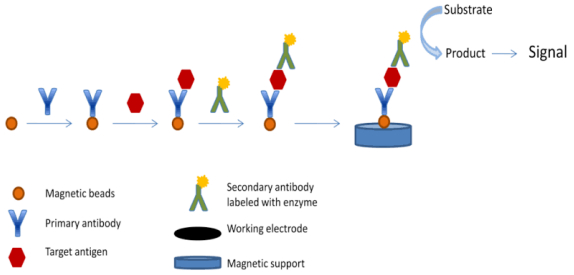

Fig.6 Immune biosensors. [51]

Enzyme biosensors:

The following enzymes, SO, LO, or FUM + SO, were cross-linked at a rate of 10 U cm-2 with 2% glutaraldehyde in 50 mmol L-1 phosphate buffer (pH 7.4) to create the enzyme layer. To achieve a density of 2 mg cm2 cm2 cm2 cm2 cm2, 100 mg mL-1 BSA was added to the mixture. The immobilization mixture (1 µL) was applied to the working Pt electrode coated with polymer, allowed to dry at ambient temperature,

and then kept at 4 °C in an environment saturated with water. [24]

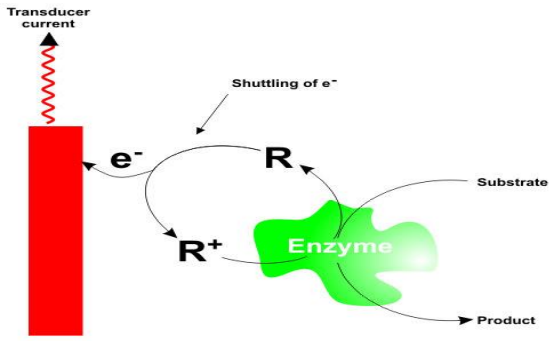

Fig. 7 Enzyme biosensors [52]

Mass-sensitive Biosensor:

They employ extremely sensitive piezoelectric crystals, sometimes referred to as piezoelectric biosensors, to identify even minute changes in mass. Piezoelectric crystals vibrate at a particular frequency when an alternating electrical current with a defined frequency is introduced. The bulk of the crystal affects this frequency in addition to the fixed electrical frequency. The frequency of oscillations is influenced by chemical reactions and is quantified as an output signal (Velusamy et al., 2010). Surface acoustic wave devices and bulk wave devices are the two main categories of mass-sensitive biosensors [18]

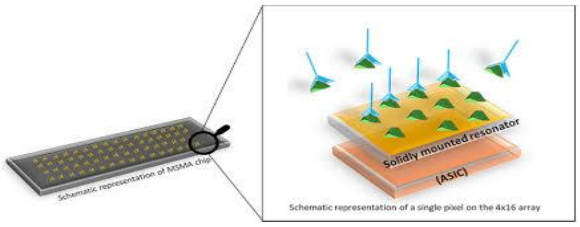

Fig.8 Mass-sensitive Biosensors [54]

Electrochemical biosensors:

The fundamental idea behind electrochemical biosensors is their capacity to identify particular chemicals. They Biosensors based on electrochemistry The fundamental idea behind electrochemical biosensors is their capacity to identify particular chemicals. They are primarily employed in the detection of hybridized DNA, glucose, and medicines that bind DNA. This method uses many kinds of chemical reactions to either produce or suppress detectable electrons or ions (Kovacs, 1998; Sethi and Lowe, 1990). According to Velusamy et al. (2010), these biosensors can be categorized as conductometric, potentiometric, or amperometric.[18]

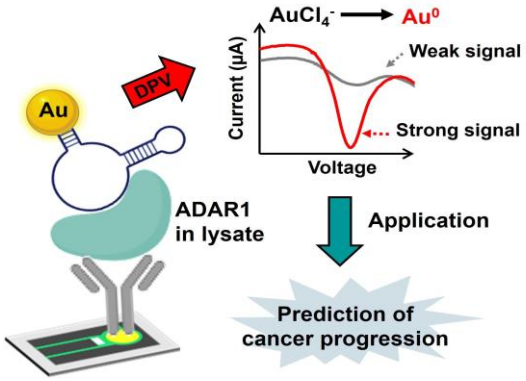

Fig 9. Electrochemical Biosensors [55]

Instrumental analysis approach

Fluorescent methods.

In order to conduct environmental screening, we suggest measuring the intensity of chlorophyll fluorescence (IChF) in specific vegetables at different times, such as prior to and following suspected military or terrorist attacks. The steps involved in direct analysis are as follows: a) setting the measurement start; b) allowing the plant to darken for three minutes prior to the measurement; c) timing the measurements for 160 seconds; and d) measuring leaf blades from the same location on the plants. In order to create the IChF curve, data from the control and experimental groups were compared using Microsoft Office 2007 analysis software. .[22, 23]

Bioluminescent methods.

The Institute of Electrodynamics of the National Academy of Sciences of Ukraine (Kiev) developed two types of stationary (computer and fiber optic-based) as well as portable chemiluminometers for regulating the reaction of bioluminescent bacteria on the effect of some chemical substances at their revealing in environmental objects. The final gadget could be applied in a field setting. Small sample aliquots can be according to conventional techniques, a variety of morphological and physiological indicators should be analyzed in order to estimate the hazardous effect as much as possible.provides the ability to assess the toxic effect over a few dozen minutes (about 20–30 minutes) by evaluating the degree of chemiluminescence in the daphnia's living medium. In this instance, aliquots are added to the living medium, and the degree of chemiluminescence should be visible within a few minutes. [19,20]

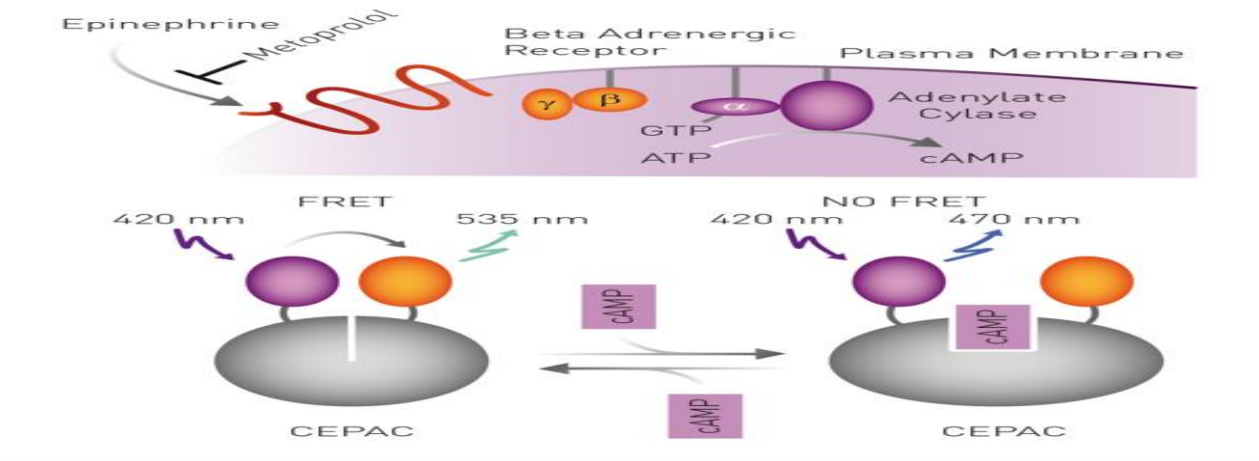

Fig10 .Bioluminescent methods.[46]

Capillary electrophoresis analysis

The Agilent 7100 capillary electrophoresis (Agilent Technologies, Waldbronn, Germany) running the ChemStation software was used for the analysis. A photometric diode array detector is integrated into the device. A fused silica capillary The capillary was conditioned for five minutes with 0.1 M NaOH, then for ten minutes with Milli-Q water and fifteen minutes with background electrolyte before being used on a regular basis. Before every run, the capillary was cleaned for three minutes using the background electrolyte. The background electrolyte was pH 5.65 and contained 0.5 mmol L-1 EDTA, 0.5 mmol L-1 CTAB, and 5 mmol L-1 phthalic acid. The system was operated at a capillary temperature of 15 °C and a separation voltage of 28 kV (negative polarity). A hydrodynamic injection was used for 3 seconds at 5 kPa (50 mbar). Indirect UV detection operating at 254 nm was used to track the analytes. By comparing the migration dates of putative peaks with those of the real standard, peaks were identified. Deionized water was used to dilute the wine samples 1:20. Three copies of each sample and standard were injected. [24]

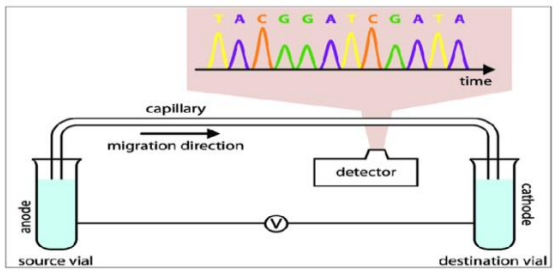

Fig11.Capillary electrophoresis analysis [56]

Recent Advancements in Pesticide Analysis

Based on the fundamentals of biosensor technology, biochips enable the precise identification and binding of a target analyte to biosensing components on a solid surface in an ordered oligonucleotides. oligonucleotides. [36] Immunosensors are less desirable for widespread detection applications due to issues such as antibody formation for extremely small compounds that cannot elicit an immune response and the instability of antibodies in adverse environmental conditions.[37]The idea for using the biochip approach to detect pesticide coumaphos was based on immunological response and surface plasmon resonance (SPR), which are components of the suppression technique. technique. technique. [40]

Application Biosensor:

Biosensors: biosensors in food technology and safety

One example of biomolecule-based assessment of toxins in food is the aforementioned microbial arsenic biosensor. It reports the presence of harmful arsenic by using the genetic regulation of a resistance mechanism that, in the presence of the hazard, instead of an arsenic transporter system, expresses GFP.

Environmental monitoring by biosensor

The BOD is important to estimate the organic resources of a water sample that can be used by microorganisms to grow and, hence, the likelihood of being polluted by organisms. It is typically measured in the water where the water is designated to be discharged.

In fermentation processes

In the medical field

Blood-glucose biosensor usage at home accounts for 85% of the gigantic world market. . A promising biosensor technology for urinary tract infection (UTI) diagnosis, along with pathogen identification and antimicrobial susceptibility, is under study.

Fluorescent biosensors

GFP-based and genetically encoded FRET biosensors play a vital role. Fluorescent biosensors are used in drug discovery programs for the identification of drugs by high-throughput, high-content screening approaches, post screening analysis of hits, and optimization of leads.

In metabolic engineering

Environmental concerns and the lack of sustainability of petroleum-derived products are gradually exhorting the need for the development of microbial cell factories for the synthesis of chemicals.

Biosensors in plant biology:

Revolutionary new technologies in the areas of DNA sequencing and molecular imaging have led to advancements in plant science. [41]

CONCLUSION

Although the introduction of pesticide chemicals was intended to save human life by boosting agricultural yields and controlling dangerous insects, weeds, and illnesses, their toxic qualities have raised serious questions about the consequences of using them. The aforementioned information amply illustrates the drawbacks of using pesticides without restriction. Biosensors have important prospects for resolving issues with pesticide measurement by conventional chromatographic techniques. However, given that a wide variety of commercial pesticides contain more than 800 active ingredients, the most significant obstacles to the transfer of pesticide biosensors from the clean research laboratory to real-life and commercial applications are related to the stability and sensitivity of the biological recognition elements, the reproducibility of the biosensors, and the variability of real samples. Enhancing the selectivity of biosensors through the use of aptamers, MIPs, microbial cells, highly specific antibodies, and genetically engineered enzymes can be successful. These biosensors may benefit from the use of nanostructured materials and microfabrication/nanofabrication methods, such as increased sensitivity, quicker reactions, and smaller instrument and sample sizes.

REFERENCE

[1] J. Ding, H. Zhang, F. Jia, W. Qin, D. Du, Assembly of carbon nanotubes on a nanoporous gold electrode for acetylcholinesterase biosensor design. Sensors Actuators B Chem 199, 284–290 (2014). https://doi.org/10.1016/j.snb.2014.04.012

[2] H. Liang, D. Song, J. Gong, Signal-on electrochemiluminescence of biofunctional CdTe quantum dots for biosensing of organophosphate pesticides. Biosens Bioelectron 53, 363–369 (2014).https://doi.org/10.1016/j.bios.2013.10.011

[3] Leyla Karadurmus1,2 ·S. Irem Kaya1,3 · Sibel A. Ozkan1.Recent advances of enzyme biosensors for pesticide detection in foods. Published 26 June 2021© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2021.

[4] P. Ramnani, N. M. Saucedo, and A. Mulchandani, ‘‘Carbon nanomaterialbased electrochemical biosensors for label-free sensing of environmental pollutants,’’ Chemosphere, vol. 143, pp. 85–98, Jan. 2016, doi:10.1016/j.chemosphere. 2015.04. 063

[5] Shaoqin Liu & Zhaozhu Zheng & Xinyu Li Advances in pesticide biosensors: current status, challenges,and future perspective Published online: 15 August 2012 Springer-Verlag 2012.

[6] Mulchandani A, Chen W, Mulchandani P, Wang J, Rogers KR (2001) Biosens Bioelectron 16:225–230

[7] Amine A, Mohammadi H, Bourais I, Palleschi G (2006) Biosens Bioelectron 21:1405–1423

[8] Castro J, Sanchez-Brunete C, Tadeo JL (2001) J Chromatogr A 918:371–380

[9] Goncalves C, Alpendurada MF (2005) Talanta 65:1179–1189

[10] Dumas DP, Durst HD, Landis WG, Raushel FM, Wild JR (1990)Arch Biochem Biophys 277:155–159

[11] Dumas DP, Wild JR, Raushel FM (1989) Biotechnol Appl Biochem 11:235–243

[12] Dumas DP, Caldwell SR, Wild JR, Raushel FM (1989) J BiolChem 264:19659–19665 554. Dumas DP, Durst HD, Landis WG, Raushel FM, Wild JR (1990)

[13] W. G. Trettnak, F. Reininger, E. Zinterl, O. S. Wolfbeis, Fiber-optic remote detection of pesticides and related inhibitors of the enzyme acetylcholine esterase, Sensors and Actuators B: Chemical, Vol. 11, Issues 1–3, 1993, pp. 87-93.

[14] Xiaoxu SUN, Lu QIAO, * Xia SUN, * Xiangyou WANG School of Agriculture and Food Engineering, Shandong University of Technology, Recent Advance of Biosensor Instruments in Pesticide Residues Rapid Detection No. 12, Zhangzhou Road, Zibo 255049, Shandong Province, P. R. ChinaPublished: 20 August 2013

[15] El-Moghazy AY, Amaly N, Istamboulie G, Nitin N, Sun G (2020) A signal-on electrochemical aptasensor based on silanized cellulose nanofibers for rapid point-of-use detection of ochratoxin A. Microchim Acta 187:535.

[16] Mohamed Amine Berkal, Corinne Nardin Pesticide biosensors: trends and progressesMohamed Amine Berkal, Corinne Nardin. Pesticide biosensors: trends and progresses. Analytical and Bioanalytical Chemistry, 2023, 415, pp.5899-5924. ff10.1007/ s00216-023-04911-4ff. ffhal-04209603f

[17] Fei Y., Sun Y.S., Li Y., Yu H., Lau K, Landry J.P., et al. Characterization of receptor binding profiles of influenza a viruses using an ellipsometry-based label-free glycan microarray assay platform. Biomolecules. 2015;5:1480–1498. doi: 10.3390/ biom5031480.

[18] Zhang Y., Chen Y., Jin G. Serum tumor marker detection on PEGylated lipid membrane using biosensor based on total internal reflection imaging ellipsometry. Sens. Actuators B Chem. 2011;159:121–125. doi: 10.1016/j.snb.2011.06.059.

[19] Pavel Damborský,Jaroslav Katrlík,Juraj Švitel Optical biosensors ,NLM or the National Institutes of Health.Published online 2016 Jun 30. doi: 10.1042/EBC20150010 https://www.ncbi. nlm.nih.gov/pmc/articles/PMC4986466/

[20] Jannat Yasmin, Mohammed Raju Ahmed, Byoung-Kwan Cho Biosensors and their Applications in Food Safety: A Review Department of Biosystems Machinery Engineering, College of Agriculture and Life Science, Chungnam National University, 99 Daehak-ro, Yuseong-gu, Daejeon 34134, Korea published July 11th, 2016

[21] Starodub N.F., Starodub V.N. “Biosensors and control of pesticides in water and foods”. Chem. And Technol. of Water, 23 (6), 612-638 (2001).

[22] Starodubb N.F., Starodub V.N. “Express control of toxic substances and pathogenic microorganisms. Immune analysis and immune sensors”, Ukr. Biochem Zhurn., 74 (4), 5-23 (2002).

[23] Nickolaj F. Starodub, Kateryna Shavanova, Andrii Karpiuk COMPLEX OF THE NEW GENERATION OF THE INSTRUMENTAL ANALYTICAL APPROACHES TO PREVENT DANGEROUS BIOTERORISM National University of Life and Environmental Sciences of Ukraine, Gerojiv Oboroni Str., 15, Kyiv, 03041, Ukraine

[24] Romanov, V., Sherer, V., Galelyuka, I., Kachanovska, M., Sarakhan, Ye. and Skrypnyk, O., “Smart portable fluorometer for express-diagnostics of photosynthesis: principles of operation and results of experimental researches,” Proc. I.TECH 2, 399-403(2007).

[25] Sherer, W. O. and Sarakhan, W. E., “Method of determination of the physiology state of plants by the method of induction of fluorescence of chlorophyll A,” Patent of Ukraine № 24908, 11 (2007).

[26] Jiri Zeravik, Zdenka Fohlerova, Miodrag Milovanovic, Ondrej Kubesa, Marta Zeisbergerova, Karel Lacina, Aleksandar Petrovic, Zdenek Glatz, Petr Skladal Various instrumental approaches for determination of organic acids in wines,Accepted Date: 4 August 2015

[27] K. R. Rogers, Recent advances in biosensor techniques for environmental monitoring, Analytica Chimica Acta, Vol. 568, Issue 1-2, 2006, pp. 222-231.

[28] Biosensors for Analytical Purposes May 14, 2019 https://www.bmglabtech.com/en/blog/biosensors

[29] Guo Zhao1,2, Hui Wang1,2, Gang Liu1,2,*Key Lab of Modern Precision Agriculture System Integration Research, Ministry of Education of China, China Agricultural University, Beijing

100083 P.R. ChinaJ. Electrochem. Sci., 10 (2015) 9790 - 9807
[30] Sajjad Ali, Muhammad Irfan Ullah, Asif Sajjad, Qaiser Shakeel, and Azhar Hussain Chapter 8 Environmental and Health Effects of Pesticide Residues.
[31] Singh, P. (2011). PhD Thesis. Guru Nanak Dev University Amritsar. India
[32] Koh, D., & Jeyaratnam, J. (1996). The Science of the Total Environment, 1, 78–85.
[33] Gavrilescu, M. (2005). Engineering in Life Sciences, 5, 497–526.
[34] Younes, M., & Galal-gorchev, H. (2000). Food and Chemical Toxicology, 38, 87–90
[35] Odukkathil, G., & Vasudevan, N. (2013). Reviews in Environmental Science and Biotechnology, 12, 421–444.
[36] Meriel, W. (2005). Pesticide: sowing poison, growing hunger, reaping sorrow (2nd ed.). Penang: Pesticide Action Network Asia and Pacific Policy Research and Analysis.
[37] Shetty, P. K., Murugan, M., & Sreeja, K. G. (2008). Current Science, 95, 457–464.
[38] Sassolas, A., Prieto-Simón, B., & Marty, J. L. (2012). American Journal of Analytical Chemistry, 3, 210–232.
[39] Van Dorst, B., Mehta, J., Bekaert, K., Rouah-Martin, E., De Coen, W., Dubruel, P., Blust, R., & Robbens, J.(2007). Biosensors and Bioelectronics, 26, 1178–1194
[40] Zhang, Z., Li, P., Hu, X., Zhang, Q., Ding, X., & Zhang, W. (2012). Sensors, 12, 9234–9252.
[41] Vo-Dinh, T. (2004). Biosensors, nanosensors and biochips: frontiers in environmental and medical diagnostics. In Proceedings of the First International Symposium on Micro and Nano Technology, Hawaii. pp 1–6
[42] Li, Y., Ma, X., Zhao, M., Qi, P., & Zhong, J. (2014). PloS One, 14, e104689. doi:10.1371/ journal.pone.0104689.
[43] By: Dr. Santosh Thakur, Lecturer, S.S. In Zoology and Biotechnology, Vikram University, Ujjain
[44] Simonian, A. L., Rainina, E. I., & Wild, J. R. (1997). Analytical Letters, 30, 2453–2468
[45] Ibrahim, H. K. R., Helmi, S., Lewis, J., & Crane, M. (1998). Bulletin of Environmental Contamination and Toxicology, 60, 448–455.
[46] R. Rawal, S. Chawla, T. Dahiya, Anal Bioanal Chem, 401 (2011) 2599
[47] P. Raghu, T. M. Reddy, B. E. K. Swamy, J Electroanal Chem, 665 (2012) 76
[48] https://www.bmglabtech.com/en/blog/biosensors 3/8/24
[49] https://images.app.goo.gl/WcRzL1JaKzSUPgka6 4/8/24
[50] https://images.app.goo.gl/XD2JcdcujfifiNSF7 4/8/24
[51] https://images.app.goo.gl/RdPLicgi8Ba1bpoC8 4/8/24
[52] https://images.app.goo.gl/K9gtw9Ta64tDiHxTA 4/8/24
[53] https://images.app.goo.gl/rq7byW3qpjj8689f7 4/8/24
[54] https://images.app.goo.gl/7VqQDVqymtLvmnoM7 4/8/24
[55] https://images.app.goo.gl/y9HhFanYxEQ8v5K57 4/8/24
[56] https://images.app.goo.gl/7vZFNhaPZdS1PNVo8 4/8/24
[57] https://images.app.goo.gl/Nk2qX4BZURPcCqh87 4/8/24
[58] https://images.app.goo.gl/gQEtcuSCyDs5371QA 4/8/24