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THE ROLE OF MICROBIAL BIOSENSORS IN PROMOTING SUSTAINABLE AGRICULTURE AND ECOLOGICAL BALANCE

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Abstract

Protection of ecological balance and sustainable agriculture approaches are of great importance in minimizing environmental impacts and efficient use of natural resources. In this context, biological applications attract attention because they offer environmentally friendly and effective solutions. Microbial biosensors constitute important alternatives especially in monitoring parameters such as pesticides and fertilizers used in agriculture and water quality. Because the use of microorganisms that are sensitive to environmental changes in microbial biosensors enables early detection of pollution and development of management strategies. At the same time, these biosensors minimize the negative effects of environmental factors on agricultural production by making low-cost, fast and high-precision measurements. At the same time, microbial biosensors contribute to the protection of natural ecosystems by providing efficient and environmentally friendly solutions for the dissemination of practices that serve sustainable agriculture. Thus, it will be possible to contribute to the sustainable development of agriculture without harming the ecological balance.

Keywords: *ecological balance; sustainable agriculture; microbial biosensors*

1. Introduction

It is believed that the exponential growth occurring in human activities could lead to imbalances in critical systems on Earth. This raises concerns that it could trigger sudden or irreversible environmental changes that could be detrimental or even catastrophic for human well-being [1]. Therefore, the relationships involving the environment, human security, and nature security have become the subject of numerous studies in recent years. Due to the global significance of environmental issues, it has become essential to establish environmental policies at both the national and international levels [2].

The link between sustainable development and ecological security

In the 1987 Bruntland Report on Our Common Future (Brundtland Report), the concept of sustainable development is defined as a development that indicates that today's needs should be met without impairing the ability of future generations to meet their own needs [3; 2] Therefore, the most effective move to ensure environmental security is to ensure sustainable development. In the elaboration of environmental security, it has been concluded that it is more useful to examine it within the framework of the distinction made at macro and micro levels. Degradation of ecosystems, global climate change and sea level rise are considered

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at the macro level, while air pollution, poor waste management and emergency resource scarcity are considered at the micro level [2].

Ecological security is a concept based on the principle of maintaining the resilience of ecosystems over time and in harmony with different species [4, 2]. This approach aims to maintain the dynamic balance of the ecosystem [5, 2]. Since the disruption of this balance will pose the risk of extinction of humans and other species, the focus is on the need to restore the balance by protecting ecosystems damaged by human activities. Although ecological security is generally considered as a sub-dimension of ecological environmental security, ecological security adopts an ecosystem-centered approach. In contrast, environmental security is human-centered, which constitutes the fundamental difference between the two concepts [6, 2].

Sustainable use of natural resources

In this context, by conserving natural resources and minimizing environmental impacts, sustainable agricultural practices constitute a critical solution that as ecological security adopts an ecosystem-centered approach to protect and balance ecosystems, it further emphasizes the importance of sustainability in agricultural practices, supports ecosystem health and ecological security.

To meet global food demand, food production needs to increase by 70% by 2050 [7, 8]. However, intensive farming practices involving the excessive use of mineral fertilizers, water, and agricultural chemicals have led to environmental pollution, soil degradation, and the depletion of natural resources. Modern agricultural practices, the use of mineral fertilizers and high use of agro- chemicals inhibit nutrient cycling in the soil [9, 8] while the adoption of such practices harms beneficial insects, plants and the soil microbiome. It also causes climate change in terms of fluctuating temperature and precipitation by polluting water systems. [10, 8]. Considering all these factors, food production practices that minimize chemical residues in the food chain and reduce environmental impact to the lowest levels pave the way for sustainable agriculture [11, 8]. In fact, sustainable agricultural practices are based on protecting natural resources against soil and water degradation, minimizing environmental pollution and protecting soil health and biodiversity. In more detail, it refers to the efficient use of farm manure, crop residues and other plant and animal products to meet human food and fiber needs by minimizing non-renewable resources. Such an approach is based on improving both farmers' quality of life and environmental health as well as enhancing economic sustainability [12, 8, 25]. In the mid-20th century, agricultural technologies guaranteed a green revolution, but at high ecological costs. They have also contributed to global pollution, adverse climate change and biodiversity loss [13, 8]. Biotechnology and microbiology offer a wide field of research to improve the quality and efficiency as well as sustainability of existing systems [14, 8].

Plants are of indispensable importance in agriculture as they constitute the primary source of food, fiber, pharmaceuticals and basic raw materials for different industrial sectors. Therefore, it is inevitable that many challenges arising from stressors, both abiotic and biotic, must be addressed to safeguard the continued health and sustainability of plant communities and the ecosystems in which they thrive [15]. In this context, microbial biotechnology provides many benefits by contributing to crop production without the use of high amounts of chemical fertilizers, pesticides, etc. [8]. The widespread use of chemicals in agricultural as well as industrial sectors further increases the release of potentially toxic pollutants into the environment. These toxic pollutants, which are also carcinogenic and mutagenic, pose significant threats to human health and ecological diversity due to their widespread distribution. For these reasons, rapid and reliable detection of these compounds is of great importance. Moreover, the use of sensitive and cost-effective techniques is a key requirement for methods aimed at reducing pollution. Although there are traditional strategies based on chromatography used for these purposes, these techniques require complex procedures and expensive specialized equipment and have the disadvantages of requiring long detection times [16].

The role of biosensors and microbial biosensors in environmental monitoring

As one of the alternative applications serving this field, biosensors are increasingly being applied in environmental analysis, as well as in many other areas such as food analysis, pharmaceutical and human health analysis. Biosensors have many advantages such as ease of transport, in situ monitoring, eliminating the need for sample transportation to the laboratory and the need for experts, minimal sample preparation requirements, sensitivity and high selectivity in small sample volumes, and the generation of a sensitive signal that is proportional to the analyte concentration [17].

Since the evaluation of key environmental variables, including bioavailability, mutagenicity, genotoxicity or cytotoxicity, is only possible with the use of living cells, whole cell (WCB) microbialderived biosensors are gaining prominence in the detection of toxic chemicals or pollutants of environmental concern. These biosensors offer enhanced analytical selectivity, lower detection limits (LOD), and greater sensitivity, among other advantages. Previous studies in this field have shown that various types of WCBs are successful in discriminating target analytes such as heavy metals, xenobiotics, pesticide residues, pesticide residues, other synthetic organic compounds/pollutants and numerous potentially toxic elements, and in environmental monitoring [16].

Microbial biosensors offer several notable benefits compared to conventional sensing methods. They are cost-efficient and require less labor, enabling the sensitive detection of bioavailable pollutant fractions. These biosensors can simultaneously monitor multiple compounds and provide rapid, precise identification of specific substances. However, they also have certain limitations, such as extended response times and challenges in maintaining cell viability and activity. The genetic stability of engineered systems is often limited, and the use of genetically modified strains may face technical and societal hurdles. Additionally, the slow diffusion of substrates and products across the cell membrane, along with environmental factors like pH, temperature, and nutrient availability, can significantly impact their performance [16]. Among the disadvantages, microbial-based biosensors may fail to detect when chemical concentrations are low or may respond only to specific groups of compounds [18, 19, 15]. Additionally, delays in response times present critical limitations for real-time detection applications. To overcome these problems, methods such as improvement of host strains [20, 15], manipulation of novel enzyme-producing strains [21, 16] and design of more sensitive promoters [22, 16] and incorporation of surface-expressed proteins have been tried [23, 16]. These innovations have led to significant advancements in improving the sensitivity, specificity, and response times of microbial biosensors [16].

Additionally, from an environmental perspective, three key advantages provided by microbial biosensors compared to other analytical methods are as follows:

- Easy and environmentally friendly analysis of individual compounds (e.g. heavy metals) or mixtures thereof, which are subject to continuous on-site monitoring on different samples
- The analysis of compounds that are difficult to analyze through conventional methods (e.g., microplastics) and the monitoring of degradation processes related to these pollutants.
- Increasing efficiency by reducing the time required for acute and chronic toxicity analysis in environmental research [17].

Developments in new biosensors based on microorganisms such as bacteria, fungi and yeasts provide an excellent alternative to physicochemical methods in the traditional sense due to their high sensitivity and specificity in monitoring the bioavailable fraction of pollutants. The main advantage of biosensors in such analyses is that continuous measurements can be carried out directly at the sampling site [24, 17]. For example, bacterial biosensor technologies are recommended as rapid methods for monitoring water and wastewater quality in EPA, USA, Mexico, Canada and European countries as an alter- native to traditional techniques. At this point, the biological material to be selected requires care because it is of great importance whether it is sensitive to the heavy metal ions being tested [17]. There are some challenges to overcome to produce biosensors of commercial interest. It should not be overlooked that a number of genetic changes in cell viability and activity, time, environmental conditions and the amount of nutrients in the medium can affect the biosensor response [16, 17].

Conclusions

As a result, the design and development of novel microbial-derived biosensors, thanks to their capacity to effectively monitor environmental pollutants, is seen as an efficient alternative to conventional sensing techniques used for this purpose. It is thought that the serious development of whole cell biosensors for potentially toxic pollutants, chemicals and heavy metals will be of great advantage, especially for use in remote or isolated environments that do not allow the transportation of test samples. In addition, real-time detection, commercialization and applications in environmental fields require overcoming technical limitations such as selectivity, increased sensitivity and stability in environmentally challenging conditions. In this direction, increasing the sensitivity and safety of microbial biosensors has significant potential for large- scale applications [16].

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References

[1] Rockström J., Steffen W., Noone K., Persson Å., Chapin III, F.S., Lambin E. et al. Foley J. Planetary boundaries: exploring the safe operating space for humanity. *Ecology and society*, 2009, Volume 14, Issue 2, pp. 32.

[2] Vural Ç. Development of environmental security. *Ankara Üniversitesi Çevrebilimleri Dergisi*, 2018, Volume 6, Issue 1, pp. 20-38.

[3] Bruntland Raporu, Report of the World Comission on Environment and De- velopment : Our Common Future, 1987, http://www.un-documents.net/our- common-future.pdf (accessed on 29 November 2024).

[4] Mc Donald M. Ecological Security. E-International Relations, 2015, http://www.e-ir.info/2015/11/28/ecological-security/ (accessed on 29 November 2024).

[5] Pirages D. Ecological Security. *Environmental Security: Approaches and Issues*, R, Floyd ve R, Matthew (ed*.).* 2013, *Routledge*, Oxon, pp. 139-153.

[6] Coldicott D., O'Brien, T. Environmental Security. *Contemporary Security and Strategy*, C, Snyder (ed.)., 2012, Palgrave Macmillan, Hampshire, pp. 72-88.

[7] Poveda J. Insect frass in the development of sustainable agriculture. A review. *Agronomy for Sustainable Development*, 2021, Volume 41 Issue 1–10. doi: 10.1007/s13593-020-00656-x

[8] Suman J., Rakshit A., Ogireddy SD., Singh S., Gupta C., Chandrakala J. Microbiome as a key player in sustainable agriculture and human health. *Frontiers in Soil Science*, 2022, Volume *2*, 821589, *doi: 10.3389/fsoil.2022.821589*

[9] Alexandridis T.K., Andrianopoulos A., Galanis G., Kalopesa E., Dimitrakos A., Katsogiannos F. et al. An Integrated approach to promote precision farming as a measure toward reduced-input agriculture in Northern Greece using a spatial decision support system. Book chapter. In *Comprehensive Geographic Information Systems*. 1 st ed. Huang B, 2017, pp. 315–52.

[10] Kughur PG., Otene V., Audu OC. Effects of intensive agricultural production on the environment in benue state, Nigeria. *IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)*, 2015, Volume 8, pp. 7–11. doi: 10.9790/2380-08810711

[11] Ray P., Lakshmanan V., Labbé JL., Craven KD. Microbe to microbiome: a paradigm shift in the application of microorganisms for sustainable agriculture. *Frontiers in Microbiology*, 2020, Volume 11:622926. doi: 10.3389/fmicb.2020.622926

[12] Farms and Land in Farms, USDA National Agricultural Statistics Service, Feb. 1999, Available online at: http://usda.mannlib.cornell.edu/usda/nass/FarmLandIn /1990s/1999/FarmLandIn-02-26-1999.pdf (accessed on 29 November 2024).

[13] Gu Y., Wei Z., Wang X., Friman V.P., Huang J., Wang X. et al. Pathogen invasion indirectly changes the composition of soil microbiome via shifts in root exudation profile. *Biology and Fertility of Soils*, 2016, Volume 52, pp. 997–1005. doi:10.1007/s00374-016-1136-2

[14] Ardanov P., Lyastchenko S., Karppinen K., Häggman H., Kozyrovska N., Pirttilä A.M. Effects of Methylobacterium sp. on emergence, yield, and disease prevalence in three cultivars of potato *(Solanum tuberosum L.)* were associated with the shift in endophytic microbial community. *Plant Soil*, 2016, Volume 405, pp. 299–310. doi: 10.1007/s11104-015-2500-y

[15] Iqbal B., Li G., Alabbosh KF., Hussain H., Khan I., Tariq M. et al. Advancing environmental sustainability through microbial reprogramming in growth improvement, stress alleviation, and phytoremediation. *Plant Stress*, 2023, 100283, https://doi.org/10.1016/j.stress.2023.100283

[16] Bilal M., Iqbal HMN. Microbial-derived biosensors for monitoring environmental contaminants: recent advances and future outlook. *Process Safety and Environmental Protection*, 2019, Volume 124, pp. 8-17, https://doi.org/10.1016/j.psep.2019.01.032

[17] Popenda A., Wiśniowska E., Manuel C. Biosensors in environmental analysis of microplastics and heavy metal compounds–a review on current status and challenges. *Desalination and Water Treatment*, 2024, 100456, https://doi.org/10.1016/j.dwt.2024.100456

[18] Biran I., Babai R., Levcov K., Rishpon J., Ron E.Z., Online and in situ monitoringof environmental pollutants: electrochemical biosensing of cadmium. *Environmental Microbiology*, 2000, Volume 2, pp. *285–290.*

[19] Van Der Meer JR., Tropel D., Jaspers M., Illuminating the detection chain ofbacterial bioreporters. *Environmental Microbiology*, 2004, Volume 6, pp. 1005–1020.

[20] Bechor O., Smulski DR., Van Dyk TK., LaRossa RA., Belkin S. Recom-binant microorganisms as environmental biosensors: pollutants detection by *Escherichia coli* bearing fab'::lux fusions, *Journal of Biotechnology*, 2002, Volume 94, pp. 125–132.

[21] Oda Y., Funasaka K., Kitano M., Nakama A., Yoshikura T. Use of a high-throughput umumicroplate test system for rapid detection of genotoxicityproduced by mutagenic carcinogens and airborne particulate matter. *Environmental Molecular Mutagenesis*, 2004, Volume 43, pp. 10–19.

[22] Norman A., Hansen LH., Sørensen SJ. Construction of a ColD cdapromoter-based SOS-green fluorescent protein whole-cell biosensor withhigher sensitivity toward genotoxic compounds than constructs based on recA,umuDC, or sul4 promoters. *Applied and Environmental Microbiology*, 2005, Volume 71, pp. 2338–2346.

[23] Medintz IL., Deschamps JR. Maltose-binding protein: a versatile platformfor prototyping biosensing. *Current Opinion in Biotechnology*, 2006, Volume 17, pp. 17–27.

[24] Lu Y., Macias D., Dean ZS., Kreger NR., Wong PK. A UAV-mounted whole cell biosensor system for environmental monitoring applications. *IEEE transactions on nanobioscience,* 2015, Volume 14, Issue: 8, pp. 811–7.

[25] Ersoy Omeroğlu E., Asli Bayer. The journey of arsenic from soil to rice. Baku State University Journal of Life Scince & Biology, 2024,v1,(1),p.65-76