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# The Role of Biosensor in Climate Smart Organic Agriculture toward Agricultural and Environmental Sustainability

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## Abstract

The application of climate smart agriculture technique has been identified as an important aspect in proffering solutions for most of the challenges to climate change mitigation as well as environmental and agricultural sustainability. Several biosensors and biosensing machineries such as nanoparticles/nanomaterials, polymers and microbes built-biosensors as well as their applications are now being used in most part of the world for solving some of the challenges in agricultural activities, food production and its sustainability. However, it is significant to assimilate multifaceted methods for sustainable development of more effective biosensors that can possibly be used for diverse applications especially in the area of climate smart organic/biological agriculture for environmental sustainability. Smart monitoring employing biosensors will ensure that biochemical and other categories of contaminants are kept at bay from conceding the quality and safety of food via the mitigation of pest and pathogens that could affect agricultural produce. Hence, this study will attempt to provide an overview of what has been done from previous studies on biosensing technologies and their wide application in climate smart organic/biological agriculture as well as their role in environmental sustainability, and this will assist in proffering useful suggestions for future research studies as future contribution to knowledge for the advancement in agricultural and environmental sustainability.

**Keywords:** agriculture, biosensors, environment, food, sustainability

## 1. Introduction

Agriculture is an imperative and steady aspect of human existence, owing to fact that human survival depends on agricultural produce. Our engagement in agricultural activities have potentially and continually been of great assistance in the production and availability of food, raw materials, chemical and several other industrial resources [1, 2]. The agricultural sector as reported by “the Food and Agriculture Organization of the United Nations (FAO)” is faced with several problems such as failures in the market system and barriers in the trade system, uneven and futile socio-economic strategies, insufficient information, availability of finance and infrastructures, pressure at a result of upsurge in the population and insufficiency resources, agronomic practices, unsustainability and dilapidation

in the environment, etc. [3]. These problems are further confronted by the influences of climate inconsistency and deviations as agriculture primarily dependent on climate variables/parameters [4–6]. Consequently, Akrofi-Atitianti et al. [5] in their study reported that agricultural sector in the developing nations (like Africa and most other developing regions) remains one of the furthestmost susceptible sectors to these problems of climate inconsistency and deviation. The issue of food safety and security as well as deficiency in food supply and climate change have a very strong relationship and according to Karimi et al. [2], it will be appropriate to always consider them together. In light of this, “the United Nations Framework Convention on Climate Change (UNFCCC)” and “the Intergovernmental Panel on Climate Change (IPCC)” have always emphasizes importance of agriculture and have incessantly placed great priority on agricultural activities [3, 4].

According to Karimi et al. [2], the influences of climate change on agricultural activities are still lagged with some uncertainties. Nevertheless, climate modification is anticipated to unpleasantly affect agricultural sector as well as other sectors and human activities globally; this would be as a result of the vicissitudes in precipitation, temperature, carbon dioxide pollination and other weather parameters/variables [7–10]. Consequently, climate adaptation techniques are ultimately essential for mitigating these increasing climate/weather actions in our environment [6, 11–14]. According to Abegunde et al. [15], climate smart agriculture is a substantial aspect in proffering solutions for both climate change mitigation, agriculture and environmental sustainability. They reported that agricultural activities can contribute significantly to climate change mitigation in the following ways:

- a. The avoidance of further deforestation and conversion or/and alteration of wetlands (marshlands or swamplands) and grasslands (savannahs).
- b. The intensification and spiraling in the storage of carbon in vegetation and soil.
- c. The reduction of current and the avoidance of future upsurges in greenhouse gases (GHGs) emissions from nitrous oxide, methane and other forms of GHGs.

Efforts genuinely gear toward the reduction of GHG emissions should be embrace agriculture. According to Fanen and Olalekan [16], some of the most important agricultural products are possible of filling the gaps between recent produces and the produces that have the potential for improving inputs and management as well as the promotion of truncated GHS emission possibilities. Climate smart agriculture has some exceptional possibilities in tackling food safety, security, adaptation and moderation tenacities [15, 16]. It has been reported that climate smart agriculture is a dependable alternative that can assist in undertaking the food insecurity issues that are alleged to be caused by the altering of the climate/weather [15, 16]. However, some developing countries have realized that some of these concepts of climate smart agriculture that have been recommended as solutions to existing problems are somehow not too suitable in their contexts as a result of some environmental capriciousness [2, 15, 16]. Besides, agriculture played a fundamental part in the alleviation of poverty and to enact major undesirable influences that climate change is expected to have on several regions globally.

Supposedly, early accomplishment in climate smart agriculture has been recognized as an indispensable means of capacity building as well as skill and guide for future opportunities [15]. However, it is desirable to have a proper meaning of what is meant by smart system before exploring to climate smart agriculture practice. Hence, according to Abegunde et al. [15] “a smart system or product is that which facilitates the interface of a system with persons/users and is able to acclimate the

framework of the user without compelling the user to acclimate to it". Smart system may comprise of the following characteristics [2, 15]:

- a. Capability to collaborate with other devices.
- b. Adaptability to acquire and improve the compatibility between its functioning and its environment.
- c. Self-sufficiency, which indicates that the system can function without intrusion from the user.
- d. Capability to network with person via natural interface.
- e. Multi-purposeful which indicates a single product is capable of executing multiple roles.
- f. Personality which indicates the system is proficient to be active and accomplish the features of credible personality.
- g. Reactivity, which indicates that the system can respond to its environment in a special way.

A smart system is capable to carry out an integral approach, from sensing to acting, to carry out optimal on-line control for performance or product quality through smart sensing techniques, besides the use of biosensors has contributed to the advancement of climate smart agriculture. Biosensors technology has the potential to improve agricultural productivity as well as food, chemical and other industrial innovative tools and techniques for the monitoring and management of swift infection disease diagnostic, the capacity enhancement of plants for the absorption of nutrients, the capacity enhancement of animal production, etc. [16]. In other to address the contribution of agricultural activities to these problems of alterations in the climate system, climate smart agriculture is gradually being indorsed in most parts of the world to assist in the integration of the economy, social and environmental extents of sustainable development in building on the three core aspects, viz.: "sustainably increasing agricultural productivity and revenues; acclimating and building resilience to climate change and; reducing and/or removing GHGs emissions relative to conventional practices" [3]. It is to be reported that climate smart agriculture has not yet be fully adopted in most developing countries (Africa inclusive); this is attributed to the limited understanding of the constraints of these countries to effectively implement the adaptation approaches faced by those involved in agricultural activities across these regions [5, 17]. Even though most developed nations of the world are beginning to adopt and apply climate smart agriculture, there is still a great deal to be done for its improvement. In light of this, biosensor in climate smart organic agriculture need to be incorporated, and this will definitely play a significant role in agricultural and environmental sustainability.

Due to the incessant growing of the world's population which according to the United Nations (UN) [18] is projected to reach around nine billion by the year 2050 from the present estimated eight billion is considered a time bomb due to the fact that upsurge in population will obviously translate to equivalent increase in food demand. Smart monitoring employing biosensors will ensure that biochemical and other categories of contaminants are kept at bay from conceding the quality and safety of food as well as the pest and pathogens that could affect agricultural produce. Biosensors are also deployed for the purpose of measuring alcohol,



carbohydrates, acids, etc. Hence, this chapter will attempt to present an assessment of what has been done from previous studies in biosensing technologies for climate smart organic/biological agriculture as well as their role in agricultural and environmental sustainability vis-à-vis food safe/security and climate change that are been explored by researchers in the area of biosensors technology for the improvement of agriculture. The limitations faced with some of the prominent techniques especially as it relates to climate smart organic/biological agriculture will be highlighted; this will evidently assist in proffering useful suggestions for future research studies as future contribution to knowledge for the advancement in agricultural and environmental sustainability.

## 2. Application of biosensors in climate smart organic agriculture

Biosensors are diagnostic devices that combine biological constituents and transducers for the discovery of sample like metabolites, drugs, microbial load, contaminants, control parameters, etc. They do so by translating biochemical reactions into quantifiable physiochemical signals such as electrical signal which in turn measure the amount of sample that are used for the discovery of analyte concentration [19–22]. Biosensors have several applications in the diverse fields or areas such as medicinal discovery and diagnosis, food protection and processing, defense and security, environmental management, etc. [21–23]. There are several types of biosensors used in the environment as it relates to soil, water and air in the area of in climate smart biological/organic agriculture and these biosensors depend on the sensing rudiments or transducers. Ever since the first discovering of the glucose biosensor in 1956, by Prof. L.C Clark Jnr, which however came in limelight commercially in 1975 [24], there are now several biosensors discovered for various commercial purposes. These contemporary biosensors have wider range of applications which offers additional specific, sensitive, fast, tangible and multiplicative results compared to previous chemical sensors [19, 20, 23].

Presently, with the advancement of nanotechnology, innovative nanomaterials are now being invented and their innovative features as well as their applications in biosensors [23, 25]. Nanomaterials-built biosensors, encompass the combination of biotechnology, molecular engineering, chemistry, physics, environmental and material science. These various fields have been of great assistance in advancing the understanding and specificity of biomolecule discovery, the ability of detecting or manipulating atoms and molecules, biomolecular recognition, pathogenic diagnosis as well as the monitoring and management of agriculture and the environment in general [23, 25]. The application of various biosensors such as nanoparticles/nanomaterials, polymers and microbes built-biosensors for agricultural and environmental activities have assisted in the reduction of the quantity of chemicals spread, reduction in nutrient losses in fertilization and upsurge in the yields via the reduction of pests and diseases for the enhancement of nutrients [26].

Biosensors are broadly categorized into two classes which are based on sensing components and transduction modes. The sensing components consist of enzymes, antibodies (immunosensors), micro-organisms (cell biosensors), biological tissues and organelles. While, the transduction modes hinge on the physiochemical variation resulting from sensing components. Accordingly, dissimilar transducer biosensors can be piezoelectric, electrochemical, calorimetric and optical [19, 27]. As reported by Reyes De Corcuera and Cavalieri [27], the common types of piezoelectric transducer biosensors are acoustic and ultrasonic; the common types of electrochemical transducer biosensors are amperometric, conductometric and potentiometric; while

the common types of optical transducer biosensors are absorbance, fluorescence and chemiluminescence. According to Arora [20], biosensors can also be categorized based on the period/order they were discovered. In these categories we have first-generation biosensors, second-generation biosensors and third-generation biosensors.

*The first-generation biosensors:* These biosensors are the modest approach involving the unswerving discovery of either increase of an enzymatically produced product or decrease of a substrate of a redox enzymes using natural mediator for electron transfer. Examples are glucose biosensor which uses enzyme glucose oxidase and oxygen detecting decrease in oxygen level or increase in hydrogen peroxide corresponding to the level of glucose.

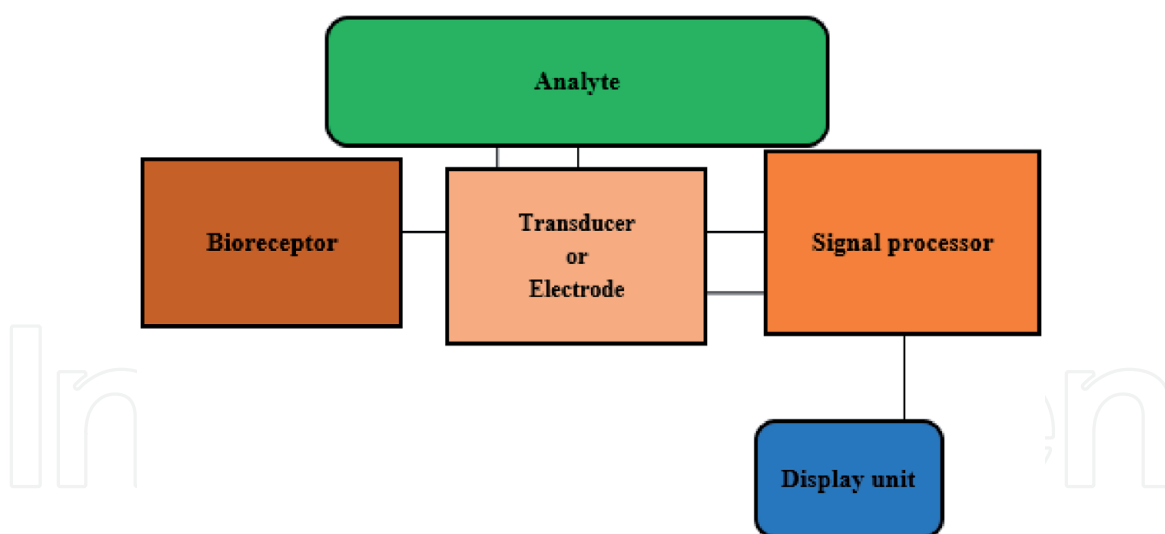
*The second-generation biosensors:* They are the biosensors that use non-natural redox mediators like ferricyanide, quinones and ferrocene for the movement of electron which increases the reproducibility and sensitivity. Examples are self-monitoring amperometric glucose biosensors.

*The third-generation biosensors:* These are biosensors wherein the redox enzymes which are immobilized on the electrode surface in such a manner that direct electron transfer is possible between the enzyme and transducer. According to Borgmann et al. [19], it uses organic conducting material like "Tetrathiafulvalnetetracyanoquinodimethane (TTF-TCNQ)".

As mentioned earlier, with the present advancement of nanotechnology, innovative nanomaterials are now being invented and their innovative features as well as their applications exist in biosensors [25]. However, it was in 1962 that Clark and Lyons invented the first biosensor that measure glucose in biological samples which utilized the strategy of electrochemical detection of oxygen or hydrogen peroxide via controlled glucose oxidase electrode and even since then, incredible improvement has been attained both in the skill involved and the applications of biosensors with advanced tactics involving nanotechnology, electrochemistry and bioelectronics [19, 21, 23, 24, 28–30]. The discovery of biosensors as an influential and pioneering diagnostic device (which has to do with biological sensing component with several applications) has undoubtedly espoused dominant importance in various fields. Its utilization has attained some significant application in the field of pharmacology, biomedicine, environmental science, food protection and processing (agriculture). Biosensors discovery have led to the development of accurate and influential diagnostic tools by means of biological sensing component as biosensor [21, 22]. According to Turner [30], the technical approaches used in biosensors are built on label-built and label-unrestricted detection. Label-built detection is primarily dependent upon the explicit features of label composites to target detection. Nevertheless, these categories of biosensors are reliable; but are habitually involve in the combination of explicit sensing components fabricated with restrained target protein. On the other hand, label-unrestricted technique allows the detection of the target molecules/particles that are not categorized or hard to tag [31, 32]. Topical interdisciplinary approaches of biotechnology and electronics technology paved way for evolving label-unrestricted biosensors for several detection approaches with numerous applications in the areas/fields of medical science and environmental science.

The major distinctive components in a biosensor which are illustrated in **Figure 1** as a block prototypical distinctive biosensor with a processor and display unit according to Mehrotra [33] are:

- a. **Detecting/Sensing Component:** This is also known as a biorecognition component; as in the case of a glucose sensor, the biorecognition component is a deactivated glucose-sensitive enzyme.



**Figure 1.**  
Block prototypical of a distinctive biosensor.

- b. **The Transducer:** The chemical, biochemical, organic, structural or physical device that interpret discrepancies in the target biophysical variables like oxygen, glucose, etc. to a physically quantifiable output signal and/or vice versa.
- c. **Signal Processor:** This could be an electrical/electronic device with/without a display system, a processor and an amplifier.

Biosensor machineries are also been applied in agriculture and environmental management/monitoring. According to Verma and Bhardwaj [34], this is another important aspect wherein biosensor technology is beginning to gain grounds. These biosensor machineries in agriculture and environmental monitoring/management will undoubtedly assist in the swift identification of pesticidal deposits in order to avert the corresponding health dangers in form of climate smart organic/biological agriculture [16, 26, 34–38]. According to Verma and Bhardwaj [34], the traditional or conventional means, such as “high-performance liquid chromatography, capillary electrophoresis and mass spectrometry” are efficient for the investigation of environmental pesticides; hitherto, there are some restrictions such as intricacy, time-intense measures, necessity of high-end devices and operative proficiencies. Therefore, even if it is believed that unpretentious biosensors have great advantages; hitherto, it is not easy to invent integrated biosensors that can analyze several categories of pesticides. Hence, steady enzyme-built biosensors have been invented for understanding the physiological (biological and physical) influence of pesticides in the environment, food security and quality management [34, 36, 39]. In the study carried out by Pundir and Chauhan [39], they reported that acetylcholinesterase inhibition-built biosensors have been invented. Over the years, for the purpose of swift analysis, this method has received great improvement with additional topical developments in acetylcholinesterase inhibition-built biosensors including immobilization means as well as other diverse approaches for fabrication [21]. In the same way, piezoelectric biosensors have been established for sensing the organophosphate and carbamate environmental influence of pesticides [36]. Organochlorine pesticides are recognized for affecting the ecosystem where pesticides such as endosulfan cause substantial environmental impairments [40]. Organochlorine pesticides have been reported to cause alteration in the reproductive system of in both male and female fish disparately [40], and in view of these facts, the discovery of biosensors for detecting aquatic ecosystem would have more consequence as a

result of biomagnification [21]. In handling this quest, electrochemical biosensors have experienced revolution with swift advances in the fabrication as well as the use of constituents like nanomaterials [21, 24].

At this juncture, it is of great significant to place distinct prominence for the selection or collection of receptors for biosensor advancement, the use of diverse transduction procedures and fast screening approaches for the applications of biosensor in agricultural activities (food production, security and safety) as well as environmental protection, monitoring and management. To aid this, biosensor fabrication appears to be vital and the improvements in this aspect have been absolutely elucidated by several researchers.

### **3. Biosensor in climate smart organic agriculture**

The main challenges faced in agriculture vis-à-vis food safety and sustainability are emphasis on three basic aspects as reported by Neethirajan et al. [38], viz.:

- a. Nanomaterials and their application in sustainable agriculture challenges.
- b. Energy sustainability challenges.
- c. Commercialization of sustainable technology challenges.

Nanotechnology is one of the foremost applications in agricultural monitoring and management. It has several valuable possessions and applicability [38]. According to Prasad et al. [41], it has all it takes to improve food safety and quality, enhance the absorption capability of soil nutrient, increase agriculture inputs, and upsurge the potentials in the miniaturized device measurement. Supposedly, nanotechnology has been used effectively for the following: precision in farming machinery (agricultural precision), smart feed management, food waste management, production of agro-chemicals/agro-materials such as nano-pesticides, nano-herbicides and nano-fertilizers, labelling and packaging of agricultural products, and several other agricultural fields [38]. According to Neethirajan et al. [38], the use of nanotechnology for agriculture as it relates to food sustainability is likely to cause some consequences in the upcoming years. This collaborated the study of Dasgupta et al. [42], that notwithstanding the benefits from the recent combination of nanomaterials/nanoparticles and activated charcoal for the enhancement of antimicrobial possessions, food grade nano-emulsion applied in fruit juice, integrated nano-microbials used as water sterilizers, effective nutraceutical nano-delivery and improved plant extracts conjugated by means of nano-packaging could have some consequences as well. A major emphasis in nanotechnology is in its application for agricultural precision (precision in farming machinery), wherein plant excerpts from its main parts such as leaves, flowers, stems and roots, from various species have been effectively integrated into nanoparticles/nanomaterials [42, 43].

Nanomaterials/nanoparticles have all it takes improve green synthesis in a sole/single-step by means of ion and metal diminishing implications; this according to Prasad et al. [41], is auspicious for the application of room temperature, easy-use, adjustable and climbable as well as eco-system friendly. During green synthesis, co-enzymes and solvable metabolites like phenolic composites, alkaloids as well as terpenoids are wholly condensed to nanoparticles/nanomaterials. Intrinsically, nanoparticles/nanomaterials are known as “magic bullets” resulting in improved plant development, location precise delivery of nutrients and amplified plant infection or disease resistance.



One of the utmost substantial challenges in nanotechnology is in the development of consistent risk-advantage evaluations by means of standardized assessment and procedures. The establishment of reliable and standardized procedures in nanomaterial/nanoparticle measurement, classification and assessment of their effect on living organism and the environment as well as the involvement of all relevant stakeholders such as farmers, agents of food industries, non-governmental organizations etc. in a dialog of public support and consumer acceptance [41, 44]. These challenges in sustainable energy can be effectively taken care of by the application biological or organic solutions. According to Adesina et al. [37], some main applications have been explored in applied organic or biological for the generation of energy:

- a. Biofuels could be produced, deposited, transformed and renewed to bio-electricity in order to expressively diminish the cost of producing solar electricity. This can be accomplished by means of leveraging through the intake of  $H_2$  or electron lashing carbon fixing metabolism, to simplify the combination by means of photovoltaics effectiveness in a process known as electro-photosynthesis [42].
- b. Hydrogen-built electrosynthesis is one of the furthestmost efficacious bioengineering energy creation set-ups. It exhibits exceptional properties such as high effective bioenergy storing capacity for electrical energy of about 80%, lengthy distance transportability with least energy forfeiture, hydrogen oxidation in microorganisms involving “Nicotinamide Adenine Dinucleotide ( $NAD^+$ ;  $C_{21}H_{27}N_7O_{14}P_2$ )” decrease diminishing potential discrepancy and affordability as a result of lesser cell-protein necessities of hydrogen oxidation [38].
- c. Electron transmission can extracellularly arbitrate electro-synthesis efficiently. This can be done reproducibly by means of a nanostructured surface to simplify the of creation bio-film. It could prance the necessity of protracted surface area and improve the transfer of hydrogen electron [38].
- d. Applied organic or biological energy creation would be significantly improved by means of the invention of several other machineries. Such innovative machineries are; gene engineering, whole genome engineering, protein engineering, and biosensing [38].

These innovative machineries will curiously enhance the development, production and generation biofuel. Apparently, since one of the furthestmost protuberant applications of applied biology is in the area of sustainable energy; hitherto, expectedly biofuel is to become the furthestmost positioned procedures in for apprehending and storing solar energy with minimum costs [38]. Presently, the challenges facing the development, production and generation biofuel are: the energy generation effectiveness and scale; competence investigation in cell self-assembly as well as duplication monitoring and management, and antagonistic environmental consequences [38]. Anticipatedly, in the forthcoming years, biofuel is to advance and extend sources of traditional energy to reutilize and replicate the generating constituents of energy and to improve hybrid energy photosynthesis [38]. In **Table 1** outlines some of the aspects where biosensors are deployed in agricultural activities.

However, the commercialization or industrialization of sustainable machineries in the agri-food scope is ongoing via some core emphases such as; biosensor commercialization or industrialization, sensing technology commercialization or industrialization, and intelligent agricultural/food commercialization or industrialization (such as climate smart biological or organic agriculture) [26]. In biosensor

Transduction	Electrode	Analyte sensed	Applications
Electrochemical magnet immunosensing [45]	Magnetic graphite-epoxy composite (m-GEC)	Salmonella in milk	The GEC holds a distinct feature of hybridization that allows the pathogens' DNA to be immobilized instantly. The procedure does not need reagents, and provides swift detection.
Electrochemical magnet immunosensing [46]	m-GEC	b-lactamase resistance in <i>Staphylococcus aureus</i>	GEC products have feeble generic adsorption for either DNA samples or enzymes labels. They do not need blocking phases on the transducer's free sites to moderate generic adsorption.
Gold nanoparticle-based [47]	GEC	Salmonella IS200	This is a good substrate for enhanced and directed immobilization of biomolecules with exceptional transductive features for the fabrication of a several of electrochemical biosensors, like immunosensors, genosensors, and enzyme sensors.
Amperometric electrochemical immunoassay [48]	Platinum (Pt) working electrode, Ag/AgCl reference electrode and a Pt counter electrode.	Staphylococcus aureus in food samples such as milk, cheese, and meat	This has been proven to be fast, operative and reproducible, and can be employed to sense specific pathogenic microbes via antibodies against precise antigens.
Multiplexing optical (luminescence) [49]	na	<i>E. coli</i> O157: H7, <i>S. typhimurium</i> and <i>Legionella pneumophila</i>	The entire quantification and calibration assay period is 18 min, aiding extremely swift analyses.
High-density microelectrode array [50]	na	<i>E. coli</i> O157: H7 bacteria in food materials	It is field-deployable, easy to use, compact, and reagent-less and provides result in minutes compared to conventional procedures.
Flow-type antibody sensor [51]	quartz crystal microbalance chip	<i>E. coli</i> in drinking water, beef, pork, and dumpling	The sensor quantifies changes in frequency as a result mass deposits that are designed by antigen-antibody interface.
Acoustic-based biosensor (the Quartz Crystal Microbalance) [52]	n.a	DNA detection	This enhances the processing of time by circumventing gel electrophoresis and can be combined in a diagnostic laboratory or an automated lab-on-a-chip device for plant pathogen diagnostics as a routine detection device.

**Table 1.**  
*Biosensor applications in agricultural activities.*

commercialization or industrialization, important aspects for the determination of its commercialization or industrialization are simpler sample pre-treatment, bioreceptor steadiness, multi-detecting/multi-sensing features, impoverishment/miniaturization, quicker testing period, wireless accessibility and affordability [53]. Some the foremost properties of commercialized accessible well-known biosensors industries are their simple structure, reduced sizes and ideal potentials for “point of care” applications [38]. They target food composition, progression monitoring and management as well as food safety and security such as allergens, pathogens, toxins, pollutants/contaminants and additives have been reported that the industries for food quality biosensors purpose is primarily from the following metabolites; “glucose, sucrose, glycerol, cholesterol, creatinine, alcohol, methanol, lactate, lactose, glutamate, malate and ascorbic acid” [26, 38]. According to Bahadır and Sezgintürk [53], compared to earlier and present/modern considered biosensors in academic/research laboratories, the modern biosensors which are mostly commercialized are far further fewer indicator of the truncated achievement rates in agri-food-connected biosensor development.

The limitations encumbering biosensor development in agriculture/food sector are substantial impediments, such problems are; “mass production, sensor lifetime, component integration and handling practicability” [38]. The motives behind these restrictions are that the utmost machineries applied in present and forthcoming agriculture/food biosensing technology are in their infancy/early stages and they include; “nanotechnology, agriculture/food material science, biomimetic chemistry and microengineering”. These basic factors could assist in the determination of forthcoming biosensors industries is its safety to human well-being, which implies that it is those with limited or no human well-being effect will have their commercialization in the forthcoming years [38]. The commercialization of intelligent agriculture/food industry specifies urgent needs in new and effective procedures to guarantee food quality and safety, to economize production procedure and to diminish loss in agriculture [54].

Biosensors have been employed for the monitoring and management of remediation procedures via the determination of the parameters that influence the growth of microbes, such as nutrient accessibility, pH, metal ions, liquified oxygen and temperature [55]. Biosensors that are required for the detection of environmental contaminants on field or large scale are not difficult to handle and need little

Biosensors	Industries
BIACORE	Biacore AB located in Sweden
Model-Amp Biosens, BioITO biosens, SMAIgal	Biosensor srl located in Formello, Italy
MB-DBO, Polytox-Res, Biocounter	Biosensores SL located in Moncofar, Spain
Portable Toxicity Screen (PTS)	52 Biotechnology Ltd. located in Uxbridge, UK
Cellsense	Euroclon Ltd. located in Yorkshire, UK
DropSens- Screen printed Electrodes	DropSense located in Asturia, Spain
Model-B.LV5, Model-B.IV4	Innovative Sensor Technology located in Nevada, USA
NECi's Nitrate Biosensor	Nitrate Elimination Co. Inc. located in Michigan, USA
Optiqua EventLab™, Optiqua MiniLab™	Optisense located in Netherlands
REMEDIOS	Remedios located in Aberdeen, Scotland
SciTOX-ALPHA, SciTOX-UniTOX	SciTOX Ltd. located in Oxford, USA

**Table 2.**  
*Commercial biosensors industries for environmental monitoring and management.*

volumes of sample rather than conventional analytical procedures which required active sample pre-treatment phases [25, 56, 57]. However, the quest of effective biosensors is continuously increasing, not just in the field of agricultural and environmental sciences, but also in other fields such as medical sciences and engineering. Presently, as a result of the wide range applications of biosensors, potential markets are still been advanced and some the few available commercial biosensors industries for environmental monitoring and management are listed in **Table 2**.

#### 4. Conclusion

Climate smart agriculture purposes exceptional prospects for handling the issues of food security as well as easing the adaptation and mitigation succors for environmental and agricultural sustainability. Climate smart agriculture has been of great assistance in this regard to most developed nations. Implementing climate smart agriculture as a capable and swift climate change response is extremely vital for building capacity and achieving food security as well as sustainable agriculture and environment globally In developing nations especially those of Sub-Sahara Africa, viewing the susceptibility to the altering climatic/weather conditions, their substantial dependence on agriculture for livelihoods and the critical role agriculture play in their economic sector; they would predominantly benefit from climate smart agriculture. Considering these regions' susceptibility to the changing climatic condition, their heavy reliance on agriculture for livelihoods, and the critical position agricultural sector holds concerning food security in these nations climate smart agriculture would undoubtedly be of great assistance. Nevertheless, there is a necessity for variance methods in encouraging the acceptance and advancement of climate smart agriculture. The small-scale agricultural segment in most developing nations is categorized by a diverse inhabitant. Consequently, a solitary even method would not be suitable in advancing climate smart agriculture practices among these set of farmers. The consequence of this is that approaches to support climate smart agriculture implementation should factor in specific collective as a replacement for mainstreaming approaches globally. Consequently, all stakeholders should contemplate of employing modalities that can accommodate the diverse features of climate smart agriculture and circumvent the potential challenges that could otherwise ascend. Additionally, since climate smart agriculture development in developing countries depends on the willingness of those involved in agricultural activities, hence, there is a need for all stakeholders to understand the multi-dimensional climate change issues and the subsequent self-mobilization for evolving and executing strategies to respond to the issues at appropriate scales.

Conclusively, in spite of the numerous benefits of biosensors and biosensing machineries such as nanoparticles/nanomaterials, polymers and microbes built-biosensors in solving some of the challenges in agricultural activities vis-à-vis environmental sustainability; there is still the need to significantly assimilate multi-faceted methods in developing biosensors that can potentially be used for diverse applications in climate smart organic/biological agriculture for environmental sustainability. Therefore, it is suggested that appropriate combination of biosensing as well as bio-fabrication with non-natural/synthetic biology methods by applying either/both electrochemical, optical, bio-electronic modalities would be crucial for efficacious development of comprehensive and influential biosensors for contemporary future contribution to knowledge in the field of biosensor machinery in climate smart organic/biological agriculture for environmental sustainability.



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There is no conflict to declare.

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## References

- [1] Garnett T. Food sustainability: Problems, perspectives and solutions. The Proceedings of the Nutrition Society. 2013;**72**:29-39
- [2] Karimi V, Karami E, Keshavarz M. Climate change and agriculture: Impacts and adaptive responses in Iran. Journal of Integrative Agriculture. 2018;**17**(1):1-15
- [3] Food and Agriculture Organisation of the United Nations (FAO). Climate Smart Agriculture Sourcebook. Rome, Italy; 2015
- [4] Field CB, Barros VR, Dokken D, Mach K, Mastrandrea M, Bilir T, et al. IPCC: Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. In: Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK; New York, NY, USA: Cambridge University Press; 2014. pp. 1-32
- [5] Akrofi-Atitianti F, Speranza CI, Louis Bockel L, Asare R. Assessing climate smart agriculture and its determinants of practice in Ghana: A case of the cocoa production system. Landscape. 2018;**7**:30
- [6] Ukhurebor KE, Abiodun IC. Variation in annual rainfall data of forty years (1978-2017) for South-South, Nigeria. Journal of Applied Sciences and Environmental Management. 2018;**22**(4):511-518
- [7] Herndon JM, Whiteside M. Further evidence that particulate pollution is the principal cause of global warming: Humanitarian considerations. Journal of Geography, Environment and Earth Science International. 2019;**21**(1):1-11
- [8] Nwankwo W, Ukhurebor KE. An X-ray of connectivity between climate change and particulate pollutions. Journal of Advanced Research in Dynamical and Control Systems. 2019;**11**(8):3002-3011
- [9] Nwankwo W, Ukhurebor KE, Aigbe UO. Climate change and innovation technology: A review. Kansai University. 2020;**63**(3):383-391
- [10] Nwankwo W, Olayinka SA, Ukhurebor KE. Green computing policies and regulations: A necessity? International Journal of Scientific and Technology Research. 2020;**9**(1):4378-4383
- [11] Ukhurebor KE, Azi SO. Review of methodology to obtain parameters for radio wave propagation at low altitudes from meteorological data: New results for Auchi area in Edo State, Nigeria. Journal of King Saud University – Science. 2019;**31**(4):1445-1451
- [12] Ukhurebor KE, Olayinka SA, Nwankwo W, Alhasan C. Evaluation of the effects of some weather variables on UHF and VHF receivers within Benin City, South-South region of Nigeria. Journal of Physics: Conference Series. 2019;**1299**:012052
- [13] Ukhurebor KE, Umukoro OJ. Influence of meteorological variables on UHF radio signal: Recent findings for EBS, Benin City, South-South, Nigeria. IOP Conference Series: Earth and Environmental Science. 2018;**173**:012017
- [14] Ukhurebor KE, Nwankwo W. Estimation of the refractivity gradient from measured essential climate variables in Iyamho-Auchi, Edo State, South-South region of Nigeria. Indonesian Journal of Electrical Engineering and Computer Science. 2020;**19**(1):276-284
- [15] Abegunde VO, Sibanda M, Obi A. The dynamics of climate change

adaptation in Sub-Saharan Africa: A review of climate-smart agriculture among small-scale farmers. *Climate*. 2019;**7**:132

[16] Fanen T, Olalekan A. Assessing the role of climate-smart agriculture in combating climate change, desertification and improving rural livelihood in Northern Nigeria. *African Journal of Agricultural Research*. 2014;**9**:1180-1191

[17] Antwi-Agyei P, Dougill AJ, Stringer LC. Barriers to climate change adaptation in Sub-Sahara Africa: Evidence from Northeast Ghana and systematic literature review. *Climate and Development*. 2014;**7**:297-309

[18] United Nations [Internet]. 2019. Available from: <https://www.un.org/development/desa/en/news/population/world-population-prospects-2019.html> [Accessed: 07 June 2020]

[19] Borgmann S, Schulte A, Neugebauer S, Schuhmann W. Amperometric biosensors. In: Alkire RC RC, Kolb DM, Lipkowski J, editors. *Advances in Electrochemical Science and Engineering: Bioelectrochemistry*. Vol. 13. Germany: Wiley-VCH Verlag GmbH & Co. KGaA; 2011

[20] Arora N. Recent advances in biosensors technology: A review. *Octa Journal of Biosciences*. 2013;**1**(2):147-150

[21] Vigneshvar S, Sudhakumari CC, Senthilkumaran B, Prakash H. Recent advances in biosensor technology for potential applications – An overview. *Frontiers in Bioengineering and Biotechnology*. 2016;**4**(11):1-9

[22] Salek-Maghsoud A, Vakhshiteh F, Torabia R, Hassani S, Ganjali MR, Norouzi P, et al. Recent advances in biosensor technology in assessment of early diabetes biomarkers. *Biosensors & Bioelectronics*. 2018;**99**:122-135

[23] El-Said WA, Abdelshakour M, Choi JH, Choi JW. Application of conducting polymer nanostructures to electrochemical biosensors. *Molecules*. 2020;**25**(307):1-11

[24] Turner APF, Karube I, Wilson GS. *Biosensors Fundamentals and Applications*. Oxford: Oxford University Press; 1987

[25] Rodriguez-Mozaz S, Alda MJ, Marco MP. Biosensors for environmental monitoring: A global perspective. *Talanta*. 2005;**65**(2):291-297

[26] Antonacci A, Arduini F, Moscone D, Palleschi G, Scognamiglio V. Commercially available (bio)sensors in the agrifood sector. In: *Comprehensive analytical Chemistry*. Vol. 74. Amsterdam, the Netherlands: Elsevier; 2016. pp. 315-340

[27] Reyes De Corcuera JI, Cavalieri JR. Prototype instruments for laboratory and on-line measurement of lipooxygenase activity. *Food Science and Technology International*. 2003;**9**(1):5-9

[28] Clark LC Jr, Lyons C. Electrode systems for continuous monitoring in cardiovascular surgery. *Annals of the New York Academy of Sciences*. 1962;**102**:29-45

[29] Fracchiolla NS, Artuso S, Cortelezzi A. Biosensors in clinical practice: Focus on oncohematology. *Sensors*. 2013;**13**:6423-6447

[30] Turner AP. Biosensors: Sense and sensibility. *Chemical Society Reviews*. 2013;**42**:3184-3196

[31] Citartan M, Gopinath SC, Tominaga J, Tang TH. Label-free methods of reporting biomolecular interactions by optical biosensors. *The Analyst*. 2013;**138**:3576-3592

[32] Sang S, Wang Y, Feng Q, Wei Y, Ji J, Zhang W. Progress of new label-free

techniques for biosensors: A review. *Critical Reviews in Biotechnology*. 2015;**15**:1-17

[33] Mehrotra P. Biosensors and their applications - A review. *Journal of Oral Biology and Craniofacial Research*. 2016;**6**(2):153-159

[34] Verma N, Bhardwaj A. Biosensor technology for pesticides – A review. *Applied Biochemistry and Biotechnology*. 2015;**175**:3093-3119

[35] Long F, Zhu A, Shi H. Recent advances in optical biosensors for environmental monitoring and early warning. *Sensors*. 2013;**13**:13928-13948

[36] Marrazza G. Piezoelectric biosensors for organophosphate and carbamate pesticides: A review. *Biosensors*. 2014;**4**: 301-317

[37] Adesina O, Anzai IA, Avalos JL, Barstow B. Embracing biological solutions to the sustainable energy challenge. *Chem*. 2017;**2**:20-51

[38] Neethirajan S, Ragavan V, Weng X, Chand R. Biosensors for sustainable food engineering: Challenges and perspectives. *Biosensors*. 2018;**8**:23

[39] Pundir CS, Chauhan N. Acetylcholinesterase inhibition-based biosensors for pesticide determination: A review. *Analytical Biochemistry*. 2012;**429**:19-31

[40] Senthilkumaran B. Pesticide- and sex steroid analogue-induced endocrine disruption differentially targets hypothalamo-hypophyseal-gonadal system during gametogenesis in teleosts – A review. *General and Comparative Endocrinology*. 2015;**219**:136-142

[41] Prasad R, Bhattacharyya A, Nguyen QD. Nanotechnology in sustainable agriculture: Recent developments, challenges, and perspectives. *Frontiers in Microbiology*. 2017;**8**:1014

[42] Dasgupta N, Ranjan S, Mundekka D, Ramalingam C, Shanker R, Kumar A. Nanotechnology in agro-food: From field to plate. *Food Research International*. 2015;**69**:381-400

[43] Duhan JS, Kumar R, Kumar N, Kaur P, Nehra K, Duhan S. Nano-technology: The new perspective in precision agriculture. *Biotechnology Reports*. 2017;**15**:11-23

[44] Fraceto LF, Grillo R, Medeiros DAG, Scognamiglio V, Rea G, Bartolucci C. Nanotechnology in agriculture: Which innovation potential does it have? *Frontiers in Environmental Science*. 2016;**4**:20

[45] Liébana S, Lermo A, Campoy S, Cortés MP, Alegret S, Pividori MI. Rapid detection of Salmonella in milk by electrochemical magneto-immunosensing. *Biosensors & Bioelectronics*. 2009;**25**(2):510-513

[46] Pividori MI, Alegret S. Electrochemical genosensing based on rigid carbon composites. A review. *Analytical Letters*. 2005;**38**(15):2541-2565

[47] Brasil de Oliveira Marques PR, Lermo A, Campoy S, Yamanaka H, Barbe J, Alegret S, et al. Double-tagging polymerase chain reaction with a thiolated primer and electrochemical genosensing based on gold nanocomposite sensor for food safety. *Analytical Chemistry*. 2009;**81**(4):1332-1339

[48] Majumdar T, Agarwal S, Chakraborty R, Raychaudhuri U. Study on electrochemical immunoassay methodology for protein a: A modified approach towards detection and quantification of staphylococcus Aureus in food samples. *Research Journal of Chemical Sciences*. 2012;**2**:62-68

[49] Karsunke XY, Niessner R, Seidel M. Development of a multichannel



flow-through chemiluminescence  
microarray chip for parallel calibration  
and detection of pathogenic bacteria.  
*Analytical and Bioanalytical Chemistry*.  
2009;**395**(6):1623

[50] Radke SM, Alocilja EC. A  
high-density microelectrode array  
biosensor for detection of *E. coli*  
O157: H7. *Biosensors & Bioelectronics*.  
2005;**20**(8):1662-1667

[51] Kim N, Park IS. Application of  
a flow-type antibody sensor to the  
detection of *Escherichia coli* in various  
foods. *Biosensors & Bioelectronics*.  
2003;**18**(9):1101-1107

[52] Papadakis G, Skandalis N,  
Dimopoulou A, Glynos P, Gizeli E.  
Bacteria murmur: Application of an  
acoustic biosensor for plant pathogen  
detection. *PLoS One*. 2015;**10**(7):e0132773

[53] Bahadır EB, Sezgintürk MK.  
Applications of commercial biosensors  
in clinical, food, environmental,  
and biothreat/biowarfare  
analyses. *Analytical Biochemistry*.  
2015;**478**:107-120

[54] Vanderroost M, Ragaert P,  
Devlieghere F, De Meulenaer B.  
Intelligent food packaging: The next  
generation. *Trends in Food Science and  
Technology*. 2014;**39**:47-62

[55] Purohit HJ. Biosensors as molecular  
tools for use in bioremediation. *Journal  
of Cleaner Production*. 2003;**11**:293-301

[56] Iqbal SS, Mayo MW, Bruno JG,  
Bronk BV, Batt CA, Chambers JP.  
A review of molecular recognition  
technologies for detection of  
biological threat agents. *Biosensors &  
Bioelectronics*. 2000;**15**:549

[57] Mazzei F, Antiochia R, Botre F,  
Favero G, Tortolini C. Affinity- based  
biosensors in sport medicine and  
doping control analysis. *Bioanalysis*.  
2014;**6**:225-245