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REVIEW

BIOTECHNOLOGY AND BIOENGINEERING WILEY

Marine biological macromolecules as matrix material for biosensor fabrication

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Abstract

The ocean covers two-third of our planet and has great biological heterogeneity. Marine organisms like algae, vertebrates, invertebrates, and microbes are known to provide many natural products with biological activities as well as potential sources of biomaterials for therapeutic, biomedical, biosensors, and climate stabilization. Over the years, the field of biosensors has gained huge attention due to their extraordinary ability to provide early disease diagnosis, rapid detection of various molecules and substances along with long-term monitoring. This review aims to focus on the properties and employment of various biomaterials (carbohydrate polymers, proteins, polyacids, etc.) of marine origins such as alginate, chitin, chitosan, fucoidan, carrageenan, chondroitin sulfate, hyaluronic acid, collagen, marine pigments, marine nanoparticles, hydroxyapatite, biosilica, lectins, and marine whole cell in the design and development of biosensors. Furthermore, this review also covers the source of such marine biomaterials and their promising evolution in the fabrication of biosensors that are potent to be employed in the biomedical, environmental science, and agricultural sciences domains. The use of such fabricated biosensors harnesses the system with excellent specificity, selectivity, biocompatibility, thermal stability, and minimal cost advantages.

KEYWORDS

biomedical and environment, biosensors, marine biomaterials, polysaccharides, proteins

1 | INTRODUCTION

The ocean, which covers more than 70% of planet earth, provides a habitat for millions of species. Life in the ocean experiences unique environmental conditions, due to which these marine organisms house noble compounds including several biomaterials. These biomaterials are derived from marine microbes like fungi and bacteria, vertebrates like fish, mammals, and invertebrates like corals. The diversity in marine biomaterials has become an attraction to researchers for the development of biosensors. For example, fish skin is a rich source of collagen and bone for hydroxyapatite (HAp) (Boaventura et al., 2020). Marine algae such as blue-green algae are also reported as an excellent source of various polysaccharides, which includes alginate, chitin, chitosan, and fucoidan (Venkatesan, Manivasagan, et al., 2015). Biomaterials can be defined as any material, engineered, or natural in origin, that can supplement human body parts partly to sustain the standard of their life. These biomaterials should be secure, dependable, inexpensive, and biologically suitable and should not link with the host's biological system. Synthetic materials are usually metallic, polymeric, and ceramic, or can be composites. The biomaterials should have biocompatibility, sterilizability, functionability, and manufacturability. Marine biomaterials, however, possess all of the aforementioned properties and thus, have great potential in the development of biosensors. Nevertheless, studies have found that marine biomaterials are also frequently used

for biomedical applications such as surgery, tissue engineering, and medicaments. Marine biomaterials in accordance with their chemical nature are categorized into six classes (Figure 1).

Marine biomaterials have unique physical and chemical properties. Functionalization and modifications of marine biomaterials increased its applicability several folds in various fields like biomedical science, environment, agriculture, and biosensors as well.

Biosensors developed from marine biomaterials have been researched and used for various applications. A biosensor is a self-sufficient tool with high specificity and sensitivity for quantitative estimation of a specific chemical or organism and its toxicity (Mahato et al., 2016, 2019; Purohit et al., 2020). A typical biosensor consists of three basic components, that is, biorecognition module (consisting of biorecognition elements and sensor matrix), transducer, and processor (Chung et al., 2018; Koh et al., 2011; Mahato, Kumar, et al., 2018). Biosensors can be categorized depending on the transducing element, that is, optical, mechanical, and electrochemical (Baranwal and Chandra, 2018; Chandra, 2016; Mahato, Maurya, et al., 2018; Mahato et al., 2020; Noh et al., 2012) (Figure 2). The transducer is an element that changes one form of energy to another and produces measurable signals. The basic principle of electrochemical biosensors is to convert biological events into electrons on an electrode, which are then converted into electric signals (Chandra et al., 2013; Kumar et al., 2019; Mahato, Kumar, et al., 2018; Mandal et al., 2018; Turner, 2000). By measuring current as a function of applied voltage, voltammetric potential determines an analyte. Amperometric biosensors detect the current created when an electroactive biological element is oxidized or reduced. Potentiometric biosensors biorecognition element with a transducer recognizes the deviation in ion concentration.

An optical biosensor primarily provides a signal proportional to the concentration of the chemical being analyzed (analyte). It may employ biorecognition components from different biological materials like enzymes, antibodies, antigens, receptors, nucleic acids, entire cells, and tissues. Surface plasmon resonance (SPR), evanescent wave fluorescence, and optical waveguide interferometry detect the interaction of the biorecognition element with the analyte by utilizing the evanescent field near the biosensor surface. There are several variants in the design of optical biosensors, and this study will concentrate on a few that have been chosen for their extensive use and productivity in detecting physiologically relevant chemicals. Optical biosensors have also been used integratedly in different analytical devices. These devices usually have a biorecognition sensing element integrated with an optical transducer system. Optical based biosensing devices are based on the principle of simple light absorption, fluorescence, reflectance, Raman scattering, chemoluminescence, SPR, optical resonators, optical waveguides, optical resonators, photonic crystals, and optical fibers (Chen & Wang, 2020). Optical biosensors can detect chemical changes in an analyte or organism by estimating the variation in the absorption of light or bioluminescence (Velasco-Garcia, 2009).

Physical factors such as acceleration, tension, and pressure may be converted into an electrical charge using piezoelectric biosensors. Bioelements are coupled with piezoelectric components such as quartz crystal coated with gold electrodes. The vibrating frequency of these crystals depends on the crystal mass as well as the electrical frequency of the crystal. It produces an electrical signal of a specific frequency directly equivalent to the vibration. Though piezoelectric sensor has a disadvantage too, the surface charge produced due to oscillation, can be neutralized easily by environmental charges and current leakage. These biosensors are sensitive to temperature, as they can lead to crystal deformation and finally an electrical output (Paul & Dertein, 2018). The cantilever biosensor is the new group of emerging micromechanical biosensors, having microfabricated silicon technology. This biosensor responds to physical (pH and temperature) and chemical changes into a mechanical bending and it can be estimated easily. Thermometric biosensors are the one that measures

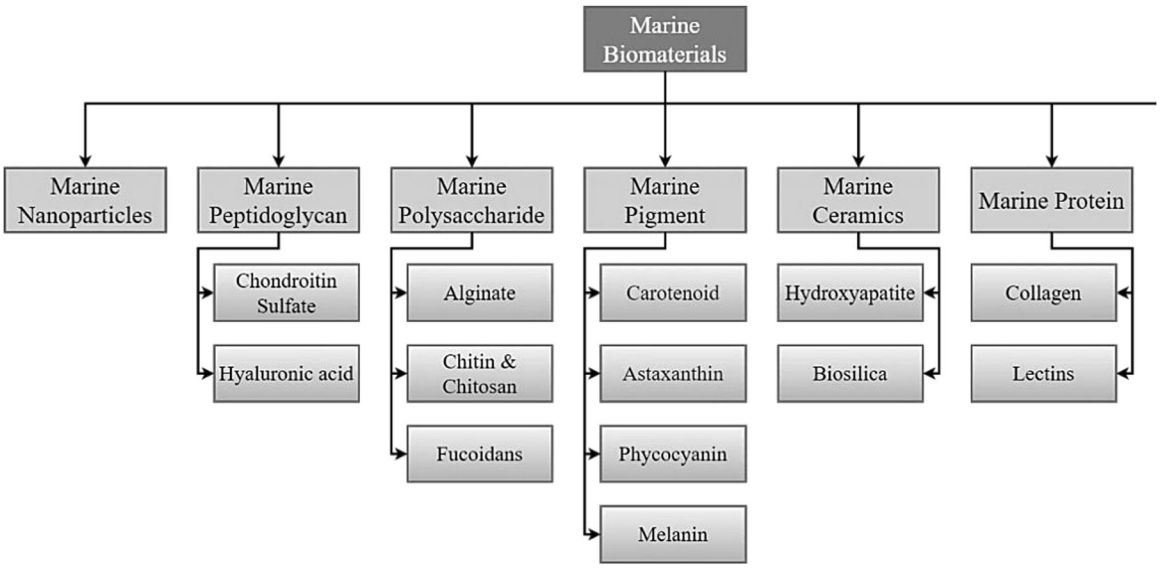

FIGURE 1 Classification of marine biomaterials based on chemical nature.

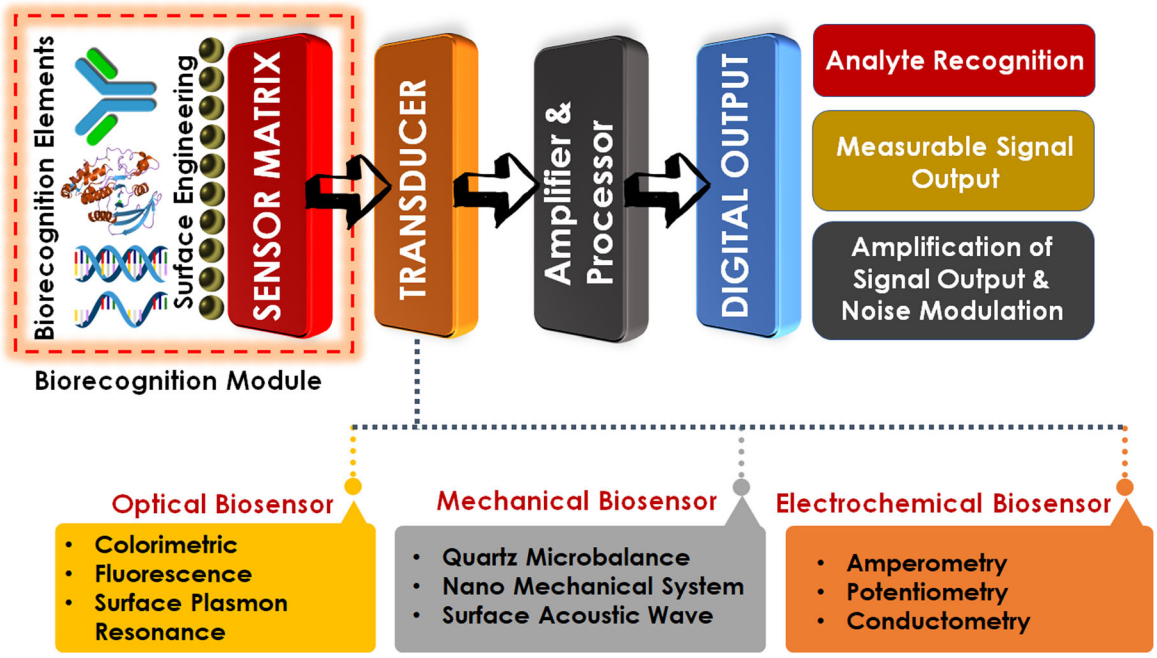

FIGURE 2 A typical construct of a biosensor and its components. Classification of biosensors based on the transducing mechanism.

the temperature change due to heat production or evolution, by analyzing enzymatic reactions.

Bioreceptors are biocatalytic molecule including enzymes, cells, antibodies, nucleic acids, and microbes that recognizes the analyte of interest. According to the bioreceptor component, biosensors will be classified into DNA biosensors, enzymatic biosensors, nonenzymatic biosensors and immunosensors, and whole-cell biosensors. Enzymatic biosensors are the one that combines enzyme with transducer. The specific immobilized enzyme identifies a specific substrate and produces a signal, the substrate can be identified by any of the transducers (optical, electrochemical, thermal, and piezoelectric) and converted into an electric signal. The nonenzymatic biosensor has metal-like platinum integrated with a transducer. Nonenzymatic sensors are without biological functional units and can be beneficial in terms of structural simplicity and mass production (Mehrotra, 2016).

Immunosensors are selective, specific, and flexible biosensors that recognize a stable compound of particular antigens or antibodies. DNA biosensors are categorized by spontaneous hydrogen bonding of the target DNA with its complementary strand based on the detection of nucleic acid sequences from infectious microbes and tiny contaminants (Asal et al., 2018).

Whole-cell biosensors are those that use living organisms as the recognition component, such as bacteria, yeast, fungus, plant and animal cells, or even tissue slices, by monitoring the initial inputs into a biological response. Whole-cell biosensors have the advantage of providing sensitive, selective, real-time, rapid, and unique data as compared to conventional chemical-based biosensors. A marine algae *Spirulina subsala* has an application in detecting metals and pesticides (Tonnina et al., 2002). As biosensors are cost-effective and sensitive, their applications have increased rapidly in the environment, medical and industrial applications (Anand Raj et al., 2020).

2 | BIOMATERIALS FROM MARINE SOURCE

Marine organism's diversity offers a huge list of biomaterials with varied properties and characteristics for biological and biomedical applications. Different biomaterials from varied marine sources have been described in this section.

2.1 | Marine polysaccharide

2.1.1 | Alginate

Alginates are components of the cell wall of seaweeds including *Laminaria, Macrocystis, Ascophyllum, Eclonia, Lessonia, Durvellia, Sargassum* as magnesium, calcium, and sodium salts of alginate. These are anionic, nontoxic, biocompatible, biodegradable, polysaccharides with controlled porosity (Gomez et al., 2009). Algin is formed by copolymerization of β-D-mannuronate and α−1-guluronate (1 → 4′)-linkage and the gelation are affected by pH. Alginates drawn out from various sources have different lengths and varying compositions of monosaccharides. Purified alginates may be applied to form different structures like fibers, beads, hydrogels, or films.

Being biocompatible, biodegradable, nontoxic, and easy to gel, alginates can be processed into various forms, such as hydrogels, microspheres, fibers, and sponges, and have been widely applied in the

biomedical field (Zhang et al., 2021). Alginate hydrogels are formed by various cross-linking associations of anionic and multivalent inorganic cationic alginates. Types and density of crosslinking in alginate change the physical and chemical properties of the alginate hydrogel. This property can be used for various biomedical applications including biosensor development. Hydrogels have a structural resemblance to extracellular matrices of living tissues and are widely studied as a scaffold. The mechanical toughness of hydrogels helps in maintaining their structure in membranes, avoids breaking when in use, and after tissue adherence. Drug delivery through alginate hydrogels is pH sensitive and in acidic conditions, gel deters the drugs tight and in neutral conditions, carboxylic group on alginate deprotonates leading to network swelling and drug release (Silva et al., 2008). Some limitations of alginate hydrogels are low porosity, swelling, degradation, mechanical rigidity, cell attachment, or detachment of bio-active molecules by physical or chemical modification. Alginate biomaterial has an application in the biomedical field (Rossi et al., 2018), tissue regeneration, wound healing (Campiglio et al., 2020), three-dimensional (3D) printing (Wang et al., 2018), in vitro modeling (Chu et al., 2018), and biosensing (Sun et al., 2020).

An intelligent and automated flexible wound dressing with embedded thermal responsive particals into an alginate hydrogel has been proposed by Mostafalu et al. (2018). He proposed the casting of a hydrogel path directly onto the flexible pH sensor and heater. Based on the data received from pH sensor, the thermal responsive release patch becomes activated and releases the antibacterial agents. This system can provide real-time information about the wound condition.

2.1.2 | Chitin and chitosan

It is the second plentiful polysaccharide associated with marine species. It is reported from the exoskeleton of *Arthropoda*, which includes *Arachnids*, *Myriapods*, *Crustaceans* (Bastiaens et al., 2019), Fungi, algae, protozoa, *Onychophora*, *Entroprocta* (horseshoe worms), *Ectoprocta* (lamp shell), *Bryozoa* (Kaur & Dhillon, 2014), *Porifera*, *Mollusca* (Rahman & Halfar, 2014), and phylum *Cnidaria* (Bo et al., 2012). Chitin is an acetylated polymer made by N-acetyl-D-glucosamine and chitosan is formed by chemical or enzymatic deacetylation of chitin (Verma & Fortunati, 2019). As per microfibril orientations of chitin, it has three different forms α-, β-, and γ. Both the polymers are highly porous, biodegradable, biocompatible, structural dependable, nontoxic, chemically inert, and less soluble. Biocompatibility, abundance, presence of functional groups in support of protein and redox mediate crosslinking, and network formation properties make chitin and chitosan a preferred biomaterial for biosensor development (Suginta et al., 2013).

Chitin and chitosan's physiochemical and biochemical qualities provide ease for molding it into membranes, gels, beads, and nanoparticles (Ifuku et al., 2009). Both are applicable in transducer surface modifiers, biosensors, drug and gene delivery, tissue engineering, stem cell technology, surgical dressings, and scaffolds (Elieh-Ali-Komi & Michael, 2016). Polymeric scaffolds of chitin and chitosan are utilized successfully for tissue repair and regeneration. Nanosilver composite scaffolds of both are used for wound healing. They have antibacterial activity and blood clotting ability as well (Madhumathi et al., 2009).

Chitosan combines with other materials like collagen or polyvinyl alcohol and improves its strength and cell attachment potential. In addition, chitosan is capable to form tough hydrogel thin film, which can be used for electrodeposition on electrode surfaces for the fabrication of micro and nano biosensors. Chitosan-derived immobilized matrices on a biosensor surface have shown excellent accuracy, selectivity, and reliability for the recognition of a varied range of biomolecules (Jiang & Wu, 2019).

2.1.3 | Fucoidans

Fucoidan is a fucose-rich sulfated sugar present in the cell wall of a huge number of seaweed including *Fucus vesiculosus*, *Sargassum stenophyllum*, *Fucus distichus*, *Hizikia fusiforme*, *Padina gymnospors*, *Analipus japonicas*, *Chorda filum*, *Caulerpa recemosa*, and *Kjellmaniella crassifolia*. Fucoidan has varied monosaccharides including xylose, galactose, mannose, and glucuronic acid. Fucoidan structure and activity vary with geographical area and seaweed source. It has several combined applications documented with nanoparticles, hydrogels, microspheres, drug-releasing systems, nanofibers, scaffolds, and microspheres for tissue design and wound dressing (Venkatesan, Lowe et al., 2015; Venkatesan et al., 2019).

2.1.4 | Carrageenan

Carrageenan is a negatively charged linear sulfur sugar acquired from algae such as *Chondrus cripus*, *Gigartina stellate*, *Hypnea*, *Halurus*, and *Solieria* (Prajapati et al., 2014). Carrageenan is made up of 3,6 anhydro galactopyranose and galactose linked by galactose α−1,3 and β−1,4 glycosidic bonds. The residue 3,6-anhyro-D-galactose is essential for forming gel by carrageenan (Venkatesan, Manivasagan, et al., 2015). Carrageenans are easily soluble in water, biocompatible, nontoxic, highly viscous, high gelling capacity, and are stable in a wide pH range. It exists in the form of nanoparticles, hydrogels, microspheres, nanofibers, wafers, films, pellets, and microspheres and it has an application in tissue designing, drug transport, wound healing, pharmaceutical formulations, and biosensing (Pacheco-Quito et al., 2020).

2.2 | Marine ceramics

2.2.1 | HAp

HAp's chemical nature is calcium phosphate and it is retrieved from varied sources including mammalian sources such as bone from camels, bovine, horses, marine sources like fish scale, shells, marine plants, algae, and mineral sources. Certain red algal forms such as

Phymatolithon calcareum (Kusmanto et al., 2008), *Amphiroa ephedra* (Oliveira et al., 2007) have calcium carbonate in their structure and are precursors of Hap.

HAp is a biocompatible, porous, renewable, and bioactive polymer and has been used as bone filler material. HAp can be mixed with a polycaprolactone to manufacture mechanically strong and porous scaffolds. HAp prepared from aquatic sources is thermostable at higher temperatures of 1200°C (Piccirillo et al., 2013). HAp provides an efficient absorption surface for functional biomolecules such as protein, DNA, and so on, and it influences the HAp surface electronic state. Surface electrical properties of HAp such as resistivity and capacitance can be useful as receptors and transducers of biosensors.

2.2.2 | Marine calcium carbonate ($CaCO_3$ or calcite)

Calcite is a precursor molecule for HAp isolated from different marine corals (*Lithothamnion glaciale*, *Coralline officinallis*, and *Phymatholithon calcareum*), calcifying algae, sponges, echinoderms, foraminifera, mollusks (*Ostrea sdulis*, *Pinctada maxima*, *Mytilus galloprovincialis*) bryozoans, fish bones, and Crustaceans shells (Andersson & Gledhill, 2013). Calcite has a resemblance to trabecular bones and is suitable for orthopedics and dentistry (Srivastava et al., 2015). It has advantages such as porosity and pore interconnectivity as well as a demerit of fast dissolution and poor structural stability (Ben-Nissan, 2003).

2.2.3 | Biosilica

Biosilica is formed by the biomineralization of silica known as frustules and formed by sponges, diatoms, radiolarians, and choanoflagellates (Schröder et al., 2008). The silica frustule structure varies in diatom species. There are approximately 3000 species of diatoms with silica exoskeleton. Some of them are *Aulacoseria ambigua*, *Stephanodiscus minutulus*, *Melosira undulata*, and *Cocconeis placentula*. Diatom silica has advantages of high surface area, porous, chemically inert, biocompatible, thermomechanical stability, lightweight, opto-photonics features and it acts as an ideal biomaterial for tissue designing, drug deliverables, and biosensors. The addition of various metals in silica frustules improves its physiochemical attributes as a nanomaterial.

Delasoie and Zobi (2019) revealed the application of biosilica frustule of genera *Aulacoseira graulata* as drug delivery vehicles to colorectal cancer cells. Other diatom species such as *Thalassiosira weissflogii*, *Coscinodiscus concinnus*, *Thalassiosira Pseudomonas*, and *Nitzschia* species also can deliver drugs and *Phaeodactylum tricornutum*, and *Odontella* are considered suitable for semiconductors (Tramontano et al., 2020). Surface functionalization as well provides a unique opportunity for sustained and controlled drug release capacities and delivery potential.

2.3 | Marine proteins

2.3.1 | Collagen

Collagen is a high molecular weight proteinaceous biomaterial, a component of connective tissues of humans, vertebrates, and invertebrates. The shape and structural properties of collagen are established by the triple helix domain. Collagens are divided into five different groups based on their structure, function, location, and other characteristics. Type I and V collagen group is allied with bone, dermis, tendon, ligaments, cornea, and Type II cartilage is associated with cartilage, nucleus pulposus, vitreous body and Type III is obtained from the vessel wall, skin, reticular fibers of lung, liver and spleen and Type IV in basement membranes.

Collagen extracted from calfskin and bones are the primary sources of industrial collagen and has a high risk of bovine spongiform encephalopathy. To overcome these problems, related to vertebrate collagen, the alternative marine collagen from skin, bones, fin, and scales of sponges and jellyfishes has been provided. Marine collagen from *Ircinia fusca* shows similarity with Type I human collagen and other marine sponges *Chondrosia reniformis* collagen resembles Type IV human collagen (Panagiotis, 2015). It shows that marine collagen is having similarities to human collagen and safer alternatives to the potential harmful bovine-originated collagen. Marine collagen can be recovered from marine vertebrates, algae, and invertebrates including jellyfish, sea urchin, octopus, squid, cuttlefish, sea anemone, prawn, starfish (Barzideh et al., 2014; Jankangram et al., 2016; Langasco et al., 2017).

Collagen from marine origin has many advantages over higher vertebrate collagen. It is pure, safe, thermostable, with interconnected porosity, and has higher denaturation temperature due to more cross-linking (Panagiotis, 2015). Collagen of Type I is paramount and has huge applications in biomedical science. Collagen can be structurally converted into porous sheets and gels. Collagen has a wide application in cosmetics, drug delivery, surgery, bio-prosthetic implants, food supplements, and tissue engineering. Collagen appears as a potential biomaterial as a scaffold in corneal, wound healing, dental, vascular tissue, and corneal damage tissue engineering. *C. reniformis* collagen has an application in the preparation of moisturizers. There is good evidence for the application of collagen biomaterials in drug delivery of target drugs to specific body parts (Patra et al., 2018).

Though collagen has some disadvantages as it can interact with cells and alter their growth or movement. To overcome this problem in collagen scaffolds, it is crosslinked with another suitable material. 3D printed fish collagen scaffold shows biocompatibility with human mesenchymal cells and fibroblast.

2.3.2 | Lectins

Lectins are a diverse group of carbohydrate-binding proteins that bind through high affinity and specific molecular sites. These lectins interact reversibly with high specificity to mono or oligosaccharides

through noncovalent linkages. Lectins can recognize and attach to specific proteins on various cell types and can identify cell development stages through flow cytometry, histochemical applications, and lectin microarrays. Lectins can indicate pathological conditions by identifying altered surface glycoproteins and glycolipids. Lectin has a multivalent binding site for the sugar moiety. Lectins are associated with varied taxa of microbes, plants, and animals. Marine lectins are structurally diverse and grouped according to structural similarity of carbohydrate recognition domain (CRD) into fucolectin type lectin, C-type lectins (CTLs), rhamnose binding lectin (RBL) lily type, ricin type, and tectonin type lectins.

Lectin producing marine species are *Aphrocallistes vastus*, *Axinella polypoides*, *Geodia cydoniu*, *Ptilota filicina*, *Tridacna maxima*, *Haliotis laevigata*, *Megabalanus rosa*, *Balanus rostratus*, *Tachypleus tridentatus*, and *Cucumaria echinate* (Ogawa et al., 2011), *Palmaria palmate*, *Solieria robusta*, *Gracilaria verrucosa*, *Cystoclonium purpureum*, *Bryothamnion seaforthii*, *B. triquetrum*, *Solieria filiformis*, *Enantiocladia duperreyi*, *Amansis multifidi*, *Hypnea musciformis*, and green algae of genus *Codium*, *Ulva lactuca*, *Caulerpa cuperssoides*, *Entermorpha prolifera*, *Ulva pertusa*, *Bryopsis plumose*, *Bryopsis hypnoides* and marine algal genus *Ptilota* (Teixeira et al., 2012).

Lectins have shown varied applications in the field of biomedical, drug delivery systems, diagnostic markers, anticancer drugs, and therapeutic activities. Cyanobacteria *Nostoc ellipsosporum* and red algae *Griffithsia sps* were used to obtain anti-HIV and HCV lectins. Marine lectins have great potential as antiviral drugs against the transmission of enveloped viruses by preventing viral entry into host cells. Marine lectin has also shown antiparasitic, immunoenhancing, immunomodulating, mitogenic, cardiogenesis, and vasorelaxant activities. In diagnostic application, lectin specificity can be utilized to differentiate between carcinoma and normal human lymphocytes and fibroblasts. Altered glycan on cells or tissues surface can be recognized using lectin-based methods such as biosensors and histochemistry. Lectin and glycan interaction in biosensors can be analyzed by signals (Dan et al., 2016).

2.4 | Marine peptidoglycan

Chondroitin sulfate and hyaluronic acid (HA) are heteropolysaccharides of class glycosaminoglycan.

2.4.1 | Chondroitin sulfate (CS)

CS is a sulfated polymer of glucoronate and N-acetylglucosamine linked by β-(1 → 3) glycosidic linkage. CS are classified according to attachment of sulfate group on Carbon atom into CS-A, CS-C, CS-E, CS-D, and Cs-B, respectively. Marine CS has been isolated from marine vertebrates including Whale, squid, salmon, skate, shark, king crab, sea cucumber, and marine invertebrates like *Cnidaria*, *Mollusca*, and *Polychaeta*. Shark fins of varied species including *Dasyatis akajei*, *Scyliorhinus torazame*, *Surus oxyrinchus*, *Prionace glauca*, *Dalatias licha*, *Mitsukurina owatoni* are used as commercial sources of CS (Abdallaha et al., 2020).

Marine CS has many advantages as it is nonimmunogenic, biocompatible, nontoxic, anti-inflammatory, and helps in cellular communication. Marine CS has an application in nerve regeneration, anti-inflammatory, antimetastatic activity, tissue engineering scaffolds, anticoagulant activity, and biosensors. In tissue engineering, it is applied for bone repair, cartilage, and cutaneous wounds. To control biodegradability CS can be mixed with other polymers to make scaffolds. CS also has pharmacological applications such as coating material for implants and hydrogel in controlled drug release (Benito-Arenas et al., 2019).

2.4.2 | HA

HA is a natural nonsulfated polysaccharide made up of α−1,4 D glucuronic acid and β−1,3-N-acetyl-D-glucosamine, linked by (1 → 3) bonds. It is part of intracellular matrix of cartilage, umbilical cord connective tissue, skeleton and vitreous humor of cartilaginous fishes, and the cell wall of marine bacteria *Streptococcus zooepidemicus* (Murado et al., 2012).

The HA activity is dependent on its size (Y. H. Liao et al., 2005). HA can hold water molecules and this property of HA gives a large range of physical, chemical, and biological activities such as biocompatibility, angiogenic, viscoelasticity, and immune stimulation. HA is also having shock-absorbing activities and acts as a lubricant for joint movement. In the skin, HA scavenges free radicals generated by the UV rays from sunlight and prevents cells from oxidative stress. HA has an application in the diagnosis of rheumatoid arthritis, cancer, and live pathologies, cosmetic fields such as plastic surgery, antiaging cosmetics, arthritis treatment intraocular surgery, and drug delivery (Srivastava et al., 2015; Vázquez et al., 2013). Though data are scarce on biosensors.

2.5 | Marine nanoparticles

In recent years, researchers have shown the great potential of marine sources in the synthesis of nanoparticles (Asmathunisha & Kathiresan, 2013), as marine nanoparticles are both biocompatible and biodegradable. These include various marine species producing nanoparticles with sizes ranging from 1 to 100 nm. Microbe-based nanoparticle synthesis allows for greater size control due to periplasmic space and vesicle compartmentalization. pH, substrate concentration, temperature, and duration of exposure to the substrate are all variables that influence intracellular particle production (Gericke & Pinches, 2006). With diverse antibacterial applications, the mangrove-derived microorganisms *Aspergillus niger*, *Penicillium fellutanum*, and *Escherichia coli* can degrade silver ions at a quicker pace (Singh et al., 2015). Other mangrove-derived yeast-like species *Rhodosporidium diobovatum* and *Pichia capsulate* are also capable of synthesizing nanoparticles (Manivannan et al., 2010; Seshadri et al., 2012). Nanoscale Chitosan also has various

applications in healthcare, agriculture, biomedical products like bonce cement and wound dressing material, food packaging, wastewater treatment, and so forth (Baranwal, Kumar, et al., 2018). Marine origin nanoparticles have shown significant applications in biomedical and biological streams including tissue engineering, cancer therapy, sensors, catalysis, drug delivery, electronic materials, and wastewater treatment (Chaudhary et al., 2020) (Tables 1 and 2).

2.6 | Marine pigments

The pigment is a secondary metabolite produced by microbes. Pigments are a mixture of chemical compounds with varied biological activities. Marine bacteria *Rubritalea squalenifaciens*, *Planococcus maritimus* produces acetylenic carotenoids, *Flavobacterium dehydrogenase*, *Halococcus*, *Halobacteria*, *Actinomycetales*, produces aryl carotenoids such as 3-hydroxy-isorenieratene, isorenieratene, and *Streptomyces mediolani*, *Monascus*, *Rhodotorula Brevibacterium linens*, *Mycobacterium aurum*, marine *Pseudoalteromonas*, marine *Actinomycetes*, and marine blue-green algae produce 3,3′-di-hydroxy-isorenieratene carotenoid.

Carotenoids extracted from *Phaffia rhodozyma* and *Haematococcus pluvialis* are used in aquaculture pharmaceuticals and food additives. *H. pulvialis* produces astaxanthins, which have an application in aquaculture feeds as well as a role in memory improvement and antiaging (Ramesh et al., 2019). As a food additive, Xanthan gum, an exopolysaccharide generated by *Xanthomonas campestris*, is utilized. Flexirubin, which is generated by Chryseobacterium and Flavobacterium, is used to treat chronic skin illness, dermatitis, stomach ulcers, and other conditions. Marine bacterial pigments can be used as pollution indicators in biosensors (Venil et al., 2014).

TABLE 1 List of some marine organisms producing nanoparticles (Singh et al., 2015).

	Species	Nanoparticles secreted
Algae	*Tubinaria conoides*	Silver, gold
	Colpomenia sinuosa	Silver
	Padina gymnospora	Silver
	Sargassum cinereum	Silver
	Gracilaria corticata	Gold
	Turbinaria conoldes	Gold
	Sargassum ilicifolium	Silver
	Ulva fasciata	Silver
	Ulva lactuca	Silver
	Urospora sp.	Silver
Cyanobacteria	*Microcoleus sp.*	Silver
	Turbinana conoides	Gold
	Phormidium tenue	Cadmium
	P. tenue	Silver
Marine animals	*Saccostera cucullata*	Silver
	Acanthella elongata	Gold
	Cod liver oil (fin fish)	Silver

3 | FABRICATION OF BIOSENSORS USING BIOMATERIALS

3.1 | Polysaccharide biosensor

Polysaccharides such as alginate, chitin, chitosan, agarose, cellulose, dextran, and HA are biomaterials with the unique property of forming hydrogels. These polysaccharide hydrogels are attractive biomaterials for biosensors because of their hydrophilicity, high protein affinity, heavy metal ion chelation, biocompatibility, ease to modify a surface chemical group, and low cost, acceptable mechanical properties, and facile fabrication method.

There is much evidence of the application of polysaccharide-based hydrogels as an immobilized biomaterial for the fabrication of bioreceptors (Tavakoli & Youhong, 2017). Physical absorption, trapping, covalent bonding, crosslinking, and other approaches can be used to immobilize bioreceptors on the hydrogel surface. Irreversible immobilization of the bioreceptor prevents detachment of it from the biosensor and if it gets detached, the hydrogel microstructure or bioreceptor activity will be destroyed (Mousty et al., 2001).

3.1.1 | Alginate-based biosensor

Alginate-based biosensors have applications in the detection of bacterial contamination in milk (Kikuchi et al., 2020), water quality estimation, and biomedical applications. To determine the glucose levels in the blood, an alginate microsphere glucose oxidase-based biosensor was designed, which utilizes glucose oxidase enzyme to estimate the glucose in vivo glucose monitoring system (Chaudhary et al., 2010). Cell-based microarray is designed by applying alginate and antibodies for application in drug discovery, toxicology, and stem cell research. Alginate-based 3D microarrays are developed for pancreatic cancer detection (Fernandes et al., 2008, 2009).

Additional evidence has been found for the detection of heavy metals by *Aliivibrio fischeri* in water, based on an alginate microsphere luminescence fiber-optic biosensor (Futra et al., 2014). The *A. fischeri* bacteria could maintain their metabolic activity for a longer time, without any change in bioluminescence. A low limit of detection for heavy metals, such as copper, cadmium, plum, chromium, gold, cobalt, and nickel, may be observed using an alginate-based biosensor ranging from 1:56 to 3100 μg/L.

Turemis et al. (2018) employed a calcium-alginate fluidic flow cell with a built-in detector *Chlorella volgaris* and the *Tetrahymen pyriformis* algae to estimate marine contaminants in real-time, using fluorescent photosynthetic photosystem II analysis. The other algal species *Laminaria hyperborean* pyeroalginate conjugate biomaterial

TABLE 2 List of marine biomaterial-based biosensors.

Sr. no.	Biosensor source	Biomaterial type	Type of biosensor	Purpose of biosensor	Role of the marine molecule	Reference
1.	Spectral emission of Lux recombinant of 11 bacterial species from four genera *Vibrio photobacterium*, *Alteromonas*, *Photorhabdus* found in marine habitats.	Pigment based, DNA based	Bioluminescent Biosensor	Heavy- metal Indicator, xenobiotics, bacteria	Optical component	Thouand et al. (2003)
2.	Microtox and luxCDABE and modified Ps. fluorescent	Transposon DNA based	Bioluminescent, pigment-based biosensor	To assess the organotonins and their breakdown products tributylin, dibutyltin, triphenyltin, diphenyltin	Optical component	Boyd et al. (1997)
3.	lux CDABE modified Ps. fluorescent	DNA based	Bioluminescent, pigment-based biosensor	Identify restrictions to bioremediation of BTEX contaminated sites.	Bioluminescent component	Sousa et al. (1998)
4.	luxCDABE modified Ps. fluorescent	DNA-based biosensor	Bioluminescent, pigment-based biosensor	Estimation of heavy metal toxicity in sewage sludge.	Bioluminescent component	McGrath et al. (1999)
5.	*Pseudomonas. fluorescent* HK44 genetically modified with luxCDABE	DNA based biosensor	Bioluminescent pigment-based biosensor.	Detection of polycyclic aromatic hydrocarbons.	Bioluminescent component	Ripp et al. (2000)
6.	Fabrication of a hydroxyapatite-based membrane originated from fish scales for designing of electrochemical membrane for the detection of KIM-1	Hydroxyapatite is sourced from natural fish scales.	Electrochemical biosensor	Sensitive determination of Kidney injury molecule 1 (KIM-1)	Matrix material of the electrode	Zhang et al. (2014)
7.	The biosensor was developed using sulfated polysaccharides such as fucoidan and dextran sulfate and antibodies for HGF were immobilized on the membrane via dicarboxy polyethylene.	Dextran sulfate and fucoidan used as sensor coatings	Electrochemical biosensor	A surface acoustic wave biosensor has been used for identifying hepatocyte growth factor (HGF/SF) in the serum-containing medium of a miniature bioreactor.	Bioconjugating material for matrix	Berger et al. (2010)
8.	Microbial fuel cell (MFC) based biosensors for determining the concentration of organic carbon.	The biofilm for the biosensor has been formed from marine sediment in the anodic compartment.	Electrochemical biosensor	Has the ability to provide an early indication of biofouling in seawater, optimize the pretreatment method for high organic carbon and monitor its effectiveness.	Biofilm for anodophilic coating	Quek et al. (2015)
9.	Marine hydrocarbon classic bacteria as a whole-cell biosensor for n-alkanes.	Marine bacteria *Alcanivorax borkumensis*	Whole-cell Biosensor	Used for detection of alkanes	Transducer	Sevilla et al. (2015)
10.	Microalgal-based recombinant bioluminescence based biosensor for estimating antifouling biocides.	Recombinant Marine green alga *Ostreocccus tauri*.	Whole cell luminescent biosensor	Application in determining antifouling biocides, i.e., diuron and Irgasol.	Bioluminescent component	Sanchez-Ferandin et al. (2013)

(Continues)

TABLE 2 (Continued)

Sr. no.	Biosensor source	Biomaterial type	Type of biosensor	Purpose of biosensor	Role of the marine molecule	Reference
11.	Nanostructured silica frustules of the Marine diatoms as optical biosensors	Modified frustule of *Coscinodiscus concinnus* bound to a specific bioprobe as antibody.	Optical Biosensors	For antibody detection	Selective bioprobe	De Stefano et al. (2009)
12.	*Helix pomatia* agglutinin	*Helix pomotia*	Electrochemical Biosensor	Colorectal cancer	Bioconjugating element	Peiris et al. (2012)

was used for physical entrapment of polyphenol oxidase (PPO). These amperometric biosensors can be used for determining catechol as the analyte, producing the sensitivity of 80 and 350 μA M^{-1} cm^{-2}, respectively (Abu-Rabeah et al., 2005).

3.1.2 | Chitin and chitosan biosensor

Chitin and chitosan hydrogels are biocompatible and easy to modify chemically. There are five categories of chitin-based biosensor (Kittle et al., 2012).

3.1.2.1 | *Electrochemical biosensor*

Chitosan is often used in the construction of electrochemical biosensors due to its solubility in moderately acidic aqueous solutions and simplicity of usage under physiological settings (Baranwal, Kumar, et al., 2018; Bhatnagar et al., 2018; Kashish et al., 2017). Chitin requires partly deacetylated chitin's amine and hydroxyl functionalities, as well as glyoxal, carbodiimide, or epichlorohydrin to cross-link individual chitin chains and bind enzymes to chitin networks. For electrostatic immobilization of enzymes, thin chitin or chitin dispersed in carbon/platinum paste are acceptable matrices (Kittle et al., 2012). Chitosan to show electrical conductivity, combine with nanoparticles like graphene, multiwall carbon nanotubes, polypyrrole, and polyaniline to enhance its electrical properties for sensing applications.

The glucose oxidase-loaded chitin films are used for quantifying the pH, oxygen, and hydrogen peroxide changes in traditional glucose sensors. Lou et al. (2020) developed an electrochemical biosensor for amlodipine identification for pharmaceutical applications using nickel molybdate nanosheets chitosan nanocomposite. Another application of a chitosan-based electrochemical biosensor with graphene was reported by Shen et al. (2020) and for the detection of dopamine by exhibiting good sensitivity with a low detection limit of 0.29 μM.

3.1.2.2 | *Chitosan-based electrochemical nucleic acid biosensors*

Screening of the biological samples for the presence of common disease markers, single-stranded target cDNA, or short-chain oligonucleotide (OND) ladders by biosensing with DNA chips and microarrays, is a recent development in medical diagnostics.

Chitosan-based DNA biosensors are formulated by the surface fixing of biotinylated probe DNA by its anionic phosphate to the cationic amino group of chitosan either by covalent bonding or affinity conjugation (Figure 3a). This sensor was used to detect Gonorrhea (a sexually transmitted illness), as reported by Singh et al. (2011). Another application of chitosan-based nucleic acid biosensor was used for detecting *Salmonella typhi* by immEobilizing ss DNA of infectious agent on graphene oxide/chitosan/indium tin oxide nanocomposite (Singh et al., 2013). Complementary, noncomplementary, and one base mismatch sequences may all be distinguished by the biosensor. For the detection of *E. coli* 0157:H7, a comparable electrochemical DNA biosensor was created by immobilizing SS *E. coli* DNA using a graphene oxide chitosan hybrid nanocomposite (Xu et al., 2017).

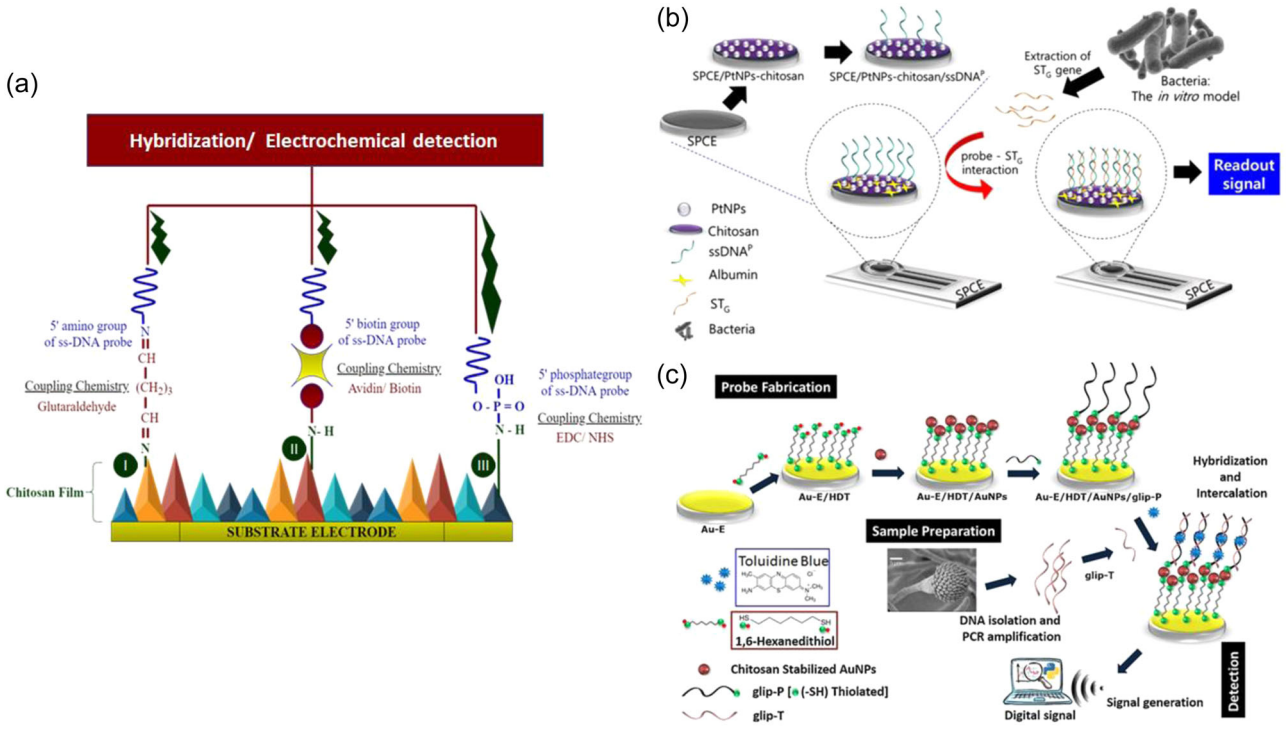

FIGURE 3 (a) DNA immobilization on electrode surfaces using chitosan (adopted from Suginta et al., 2013); (I) glutaraldehyde-based coupling chemistry is used. (II) Biotin-modified chitosan and DNA, as well as the utilization of avidin as a high-affinity bridging molecule. (III) Using ethyl(dimethylaminopropyl)carbodiimide / N-hydroxysuccinimide to connect the phosphate groups of DNAs to the amino groups of chitosan; (b) fabrication of a biosensor surface for enterotoxigenic *Escherichia coli* detection based on ssDNA anchored on PtNPs-chitosan nanocomposite (adopted from Kashish et al., 2017); (c) detailed illustration of chitosan stabilized gold nanoparticle-mediated self-assembled gliP biosensor fabrication and diagnosis of invasive aspergillosis (adopted from Bhatnagar et al., 2018).

Chitosan, being a cationic polymer are potent biomolecule complexation agents. In 2017, Kashis et al. developed a label-free electrochemical biosensor to detect *E. coli* in a highly selective manner by sensing the ST gene (ST_G) (Figure 3b). A polymerase chain reaction was used to confirm the sensor probe's capacity to detect ST_G. The biosensor was built using ST_G-specific probes mounted on a film of platinum nanoparticles chitosan nanocomposite over a screen-printed carbon electrode. ST_G hybridization was analyzed using electrochemical impedance spectroscopy (EIS) yielded an exceptionally sensitive label-free sensing module. After ST_G interaction with the highly selective ssDNA probe immobilized on the nanocomposite film, the EIS analysis revealed a considerable increase in charge transfer resistance (Kashish et al., 2017). The increase in charge transfer resistance was examined for various ST_G concentrations, revealing a dynamic range of 10^{-12}–10^{-4} M with a detection limit of 3.6×10^{-14} M. Chitosan can also be applied as a stabilizing agent for the synthesis of different nanoparticles that have been further used in the diagnostic, protein attachment in biological processes and surface adaptation of cells. In this vein, Bhatnagar et al. have developed a sensitive electrochemical nanobiosensor for Invasive Aspergillosis diagnosis by detecting the pathogenic glip target gene (glip-T) in a downsized experimental setup (Figure 3c). The sensor probe was made with 1,6-hexanedithiol and chitosan stabilized gold nanoparticles mediated self-assembly of glip probes (glip-P) on a gold electrode. The sensor's capacity to detect glip-T was evaluated using the hybridization reaction and the signal was acquired using toluidine blue as an indicator molecule. The biosensor showed a dynamic range of 10^{-14}–10^{-12} M and a detection limit of $0.32 \pm 0.01 \times 10^{-14}$ M. The developed sensor was proven to be selective, reproducible, regenerative, and compatible with the real sample.

3.1.2.3 | *Chitosan-based electrochemical immunosensors*

Electrochemical immunosensors based on chitosan are created by immobilizing antibodies or antigens on the electrode surface of chitosan. One of the advantages of chitosan is that the number of amino sites accessible for covalent protein attachment to chitosan materials may be varied across a large range merely by changing the degree of deacetylation of the variety (Figure 4a). The fungal hepatocarcinogen aflatoxin B1 (Masoomi et al., 2013), botulinum neurotoxin A (Afkhami et al., 2017), diarrhea triggering bacteria *Shigella flexneri*, ochratoxin A, hepatitis B biomarkers, cancers and iron content of the blood (Liang et al., 2014) are detected and monitored by using electrochemical immunosensors.

3.1.2.4 | *Chitosan-based electrochemical enzyme biosensor*

Chitosan appears as a porous polymer for adherence of enzymes by its polycationic chains to form the biosensor. Cross-linking drugs such as GL, carbodiimide, NH, epichlorohydrin or GL, NH or cyanuric acid

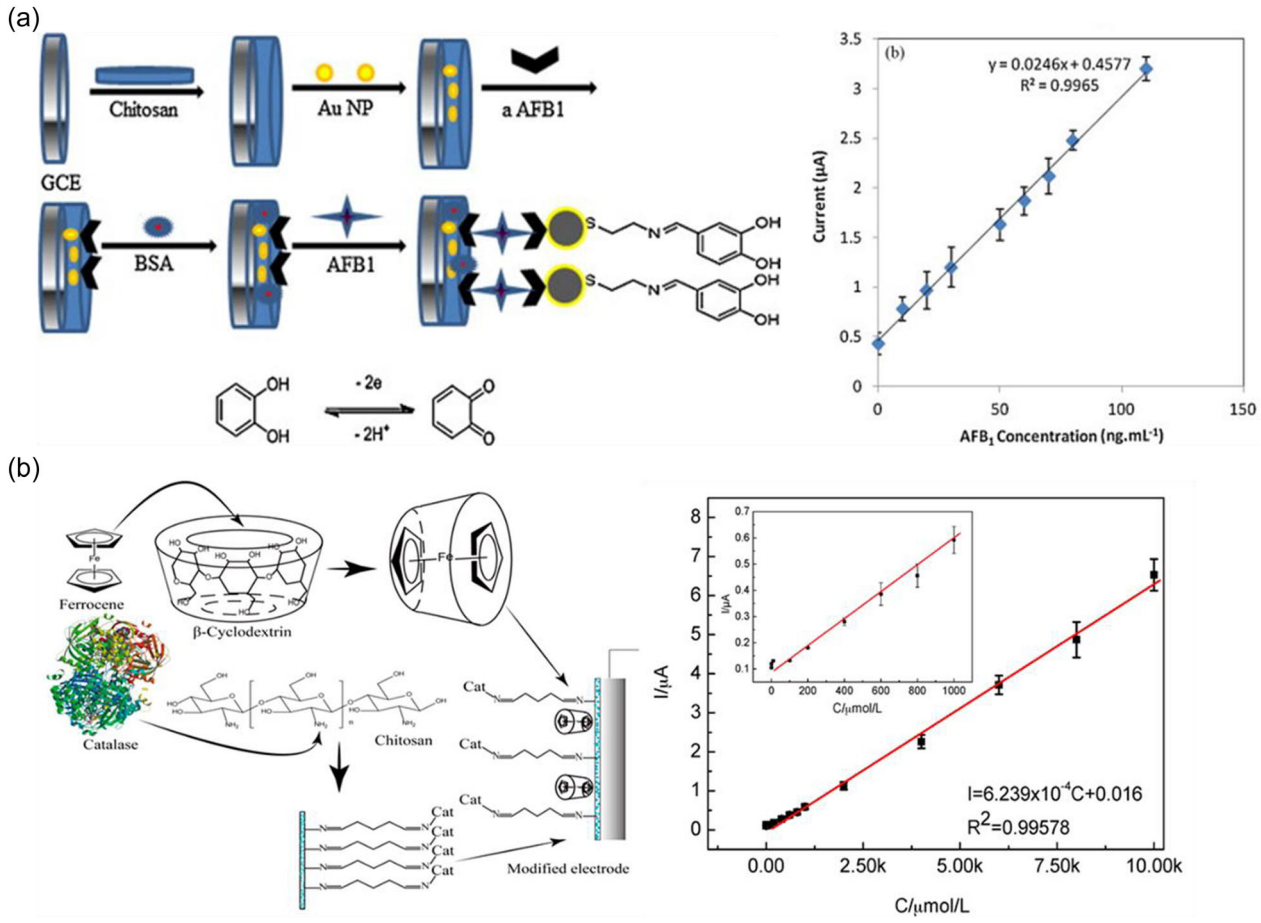

FIGURE 4 (a) Illustration of the fabrication step of glassy carbon electrode/chitosan/AuNP/a AFB_1–AFB_1–a AFB_1–catechol–Au–Fe_3O_4 immunoelectrode for determination of aflatoxin B_1 as a model antigen. (Inset) the calibration plot of the changes of the current response via concentration of AFB_1 in buffer (adopted from Masoomi et al., 2013). (b) Schematic diagram of construction of the chitosan-immobilized-enzyme and β-cyclodextrin-included-ferrocene composite electrode. (Inset) The relationship between the reduction peak current and H_2O_2 concentration (adopted from Dong et al., 2017).

are suitable for this attachment, for example, a cross-link such as GL and GL. The adhesion does not interfere with enzyme movement and function. The important aspect in connecting chitosan with various chemical groups is the abundance of functional groups and pH solubility. Many applications of chitosan-based electrochemical enzyme biosensor were reported, including for dopamine release in the brain of rats (Njagi et al., 2008), detection of hydrogen peroxide via catalase immobilized on chitosan-β-cyclodextrin (Dong et al., 2017) (Figure 4b) and chlorophenol determination via laccase immobilized on ZnO-chitosan nanocomposite (Mendes et al., 2017).

3.1.2.5 | *Chitosan-modified voltammetric electrodes for trace analysis*

Chemically modified chitosan with electrochemical voltammetry has enormous potential as efficient sorbent material for the detection of environmental pollutants including pesticides, heavy metals, and dyes. The current difference between the reference and working electrodes created by the reduction or oxidation of an electrochemical biosensor is measured using a voltammetric biosensor. Anodic stripping voltammetry, sweep voltammetry, and cyclic voltammetry are used for determining heavy metals with great sensitivity. Janegitza et al. (2009) demonstrated the use of chitosan-supported adsorptive stripping voltammetry for the quantification of Cu (II), Cd (II), and Hg (II) with good sensitivity in the electroanalysis of heavy metals.

Nickle oxide coupled chitosan electrochemical biosensor has been applied for the estimation of an infective pathogen like *E. coli* and *S. typhi* from the environment and clinical samples (Solanki et al., 2015). A large number of chitin and chitosan-based biosensors have been designed till now and the above-mentioned are some of the representatives in this category (Suginta et al., 2013).

3.1.3 | Fucoidan biosensor

For the manufacture of the drug delivery system, Kurosaki et al. (2009) used fucoidan as a matrix material. Berger et al. (2010) have also used fucoidan and dextran sulfate as a biomaterial for HGF

sensor coating. HGF has been attached specifically to sulfated polysaccharide fucoidan for the identification of hepatocyte growth factors in the serum-containing medium of a small bioreactor for culturing hepatocytes. Fucoidan-coated HGF biosensor has shown the highest sensitivity and low-cost alternative to the use of antibodies (Berger et al., 2010).

3.1.4 | k-carrageenan biosensor

For nonaqueous solvents, the k-carrageenan gel has been considered an appropriate choice for enzyme immobilization in organic phase electrode construction (Campanella et al., 1999). In another study, Campanella et al. (2000) have reported, carrageenan biomaterial as an immobilizing membrane for superoxide dismutase enzyme, which determines superoxide radical received through amperometric gaseous electrode for oxygen or hydrogen peroxide. Other biosensor application includes the reduction of pathogen contamination in poultry food (Medina, 2004), radical scavenging properties in hydrophobic compounds (Campanella et al., 2001), and low-level urea detection (Taşaltın et al., 2020). Another enzymatic biosensor for glucose detection from glucose-spiked saliva samples is a bio nanocomposite film comprising a polyelectrolyte complex (PEC) doped with gold nanoparticles containing glucose oxidase (Rassas et al., 2019).

3.2 | Marine protein biosensor

3.2.1 | Lectin biosensor

Lectin-based biosensors determine the measurable signal by estimating the conversion of lectin-carbohydrate interactions. Lectins have a high affinity to multivalent oligosaccharides. Lectins' extremely specific binding to terminal carbohydrate moieties on cell surfaces and protein aggregates is used in physiological and pathological studies, such as virus and bacterium detection and glycol profiling of serum glycoproteins. Electrochemical lectin-based biosensors can be used to diagnose illness and pathogens by detecting biomarkers (Coelho et al., 2017), as well as biorecognition of glycan in viral proteins (Cesewski & Johnson, 2020).

SARS-COV-2 envelope glycoprotein might be exploited for early detection using lectin-based biosensors. Another use of lectin-based electrochemical biosensors includes the use of cyclic voltammetry and impedance to detect norovirus (nonenveloped virus) in feces samples without showing cross-reactivity with hepatitis A or E (Hong et al., 2015). The impedimetric lectin-based biosensor can also be applied for differentiating the chikungunya virus, Zika virus, yellow fever, and DENV-2 in serum-based samples (Simao et al., 2020).

J. H. Liao et al. (2016) described a lectin-based biosensor made from the marine mollusk *Crenomytilus grayanus* (CG) that may be used to diagnose and treat cancer. The CGL crystal can attach to three ligands: galactose, galactosamine, and globotriose (Gb3), and it may be utilized to recognize Gb3 on the surface of breast cancer cells, causing them to die. Peiris et al. (2012) developed a lectin-based biosensor using N-acetylgalactosamine lectin from the Roman snail *Helix pomatia* agglutinin (HPA) (*H. pomatia*). This HPA-based biosensor can have an affinity for metastatic SW620 cells and nonmetastatic SW480 in different molar ranges.

This approach is the latest approach for the selective determination and quantification of cancer-specific glycans and lectin.

3.2.2 | Collagen-based biosensor

Marine collagen is reported to be nontoxic, environmentally friendly, low inflammatory response, and biocompatible. There are many reports of marine collagen biomaterial in tissue engineering, though there is a scarcity of data on the marine collagen-based biosensor.

Zong et al. (2006) reported a biosensor using chrome waste from leather waste in a tannery. The collagen grafted biosensor which has been discovered is found to be biocompatible, thermally stable, highly sensitive, and with improved selectivity. Due to the advantages offered by hybrid collagen, zirconia nanoparticles collagen composite was reported to prepare amperometric glucose biosensors.

3.3 | Marine ceramics-based biosensors

3.3.1 | HAp-based biosensors

HAp surface provides an excellent ability to absorb functional molecules such as proteins, DNA, and so forth. Nishikawa et al. (2006) have shown that sodium HAp is one of the most effective biomaterials for biosensor applications. By utilizing HAp nanoparticles and chitosan nanocomposite, Lu et al. (2010) created a new tyrosinase-based biosensor. By monitoring the reduction signal of the bio-catalytically generated quinone species at −0.2 V, the constructed biosensor was used to identify phenolic chemicals (vs. saturated calomel electrode). Sudhan et al. (2019) utilized the tannery HAp-graphene multiwalled carbon nanotube's sensing capability to detect a chemical that represents risk factors for sudden infant death syndrome (SIDS). This sensor helps in estimating the risk factors associated with SIDS.

3.3.2 | Biosilica-based biosensors

Diatom frustules are composed of nanostructured amorphous silica, and their surface may be functionalized and tailored for biosensor applications. Due to the easy availability of diatom frustules in every pond water, it assures its low cost. Rea and De Stefano (2019) reported the fabrication of silver nanoparticles on the diatom surface, which produces huge plasmonic hotspots that increase the Raman effect. The molecular probes are covalently attached to the diatom cell wall (DNA strands, proteins, enzymes, antibodies, and so on). Selveraj et al. (2018) found that nitroaromatic compounds could be

identified with excellent sensitivity and specificity using amine-removed diatom frustules from *Nitzschia sp* They also reported the detection of *S. typhi* by the same diatomic species. Leonardo et al. (2017) reported fixation of antibody functionalized diatoms on gold electrodes. Changing the electrodeposition parameters can influence diatom immobilization, orientation, and yield. For methyl parathion electrochemical detection, Gannavarapu et al. (2019) utilized a diatom *P. tricornutum* surface reformed by ZrO_2 by precipitating in a solution. The hybrid diatom-based electrode offers the benefit of detecting pollutants, chemicals, and enzymes at the picomolar level.

3.4 | Marine peptidoglycan-based biosensors

3.4.1 | HA-based biosensors

HA, is an anionic, nonsulfated glycosaminoglycan, antifoulant biomaterial for electrochemical biosensors (Liu et al., 2014). HA disaccharide unit facilitates the hydrogen bonding of bioreceptors. Joung et al. (2013) developed an impedimetric label-free immunosensor by utilizing nanoporous HA membrane for detection of *E. coli* O157:H7 pathogen from whole milk.

3.4.2 | CS-based biosensors

Zhao et al. (2020) have reported ultrasensitive and ultra-selective polyethylene glycol (PEG) CS biosensor, for identification of *Mycoplasma ovipneumonia*. This sensor is more sensitive than the earlier sensors in detecting *M. ovipneumonia* in whole serum thus, offering a wide range of applications. The CS-based biosensor exhibits high selectivity, reproducibility, storage stability, and analytical performance with a wide range of concentrations (1017–1012 M) in the buffer.

3.5 | Marine nanoparticles-based biosensors

Marine Nanomaterial based biosensors should be integrated within tiny biochips, which enhances the functionality of biosensors as well as made portable, pocket friendly, and easy to use (Singh et al., 2015).

Elgamouz et al. (2020) have prepared *Noctiluca scintillans*-mediated AgNP's biosensor for sensing hydrogen peroxide. It was discovered that the breakdown of hydrogen peroxide on AgNP's catalytic surface is pH, temperature, and time-dependent. Using Abs calibration curves, the test assay correctly predicts repeatable levels of H_2O_2 in unlabeled samples in three distinct ranges—mM, M, and nM.

Algal synthesized gold nanoparticles are utilized in the biosensing of cancer diagnostics by analyzing the type and quantity of hormones in the human body. The algae-produced nano Au–Ag alloy has substantial electrical catalytic activity against 2-butanones and offers a platform for the early phase cancer development in which the biosensor detects the initial stages by recognizing the presence of malignant cells.

In separate research, the AuNPs biosensor from *Hypnea Valencia* was shown to be capable of detecting human chorionic gonadotrophin (HCG) in urine samples from pregnant women in an HCG blood pregnancy kit (Kuppusamy et al., 2014). Platinum NPs from *S. myriocystum* can be used as biosensors to track the amount of adrenaline in the body, which is a hormone-based medicine used to treat allergies, asthma, and heart attacks (Sharma et al., 2019).

3.6 | Marine pigment-based biosensors

A whole-cell biosensor for cadmium assessment utilizing a colorimetric technique has been created using a genetically engineered red pigment generating bacterium *Deinococcus radiodurans* (Joe et al., 2012). Lac Z reporter gene cassettes were created by combining the promoter regions of inducible genes that detect high levels of Cd. The reporter cassettes were transplanted into *D. radiodurans* R1 to assess promoter activity and specificity. It can detect cadmium in concentrations ranging from 1 to 10 mM. LacZ expression was increased up to 100 IM Cd, but it swiftly decreased with increasing concentrations. The presence of Cd reforms the color of the sensor bacterium strain (KDH081) from light yellow to red, but the addition of other metals has no impact. With a Cd detection range of 50 nM to 1 mM, the color shift is produced by the formation of red pigment and can be observed with the naked eye. By introducing a promoter region that may be utilized as a possible colorimetric system-based biosensor, there is a good chance of developing a novel pigment-based vector and host system.

4 | FUTURE PROSPECTS AND CONCLUSION

Marine biomaterials are attracting tremendous attention from researchers as they offer a cost-effective and biocompatible potent source for therapeutics, regenerative medicine, the food industry, and biosensors. The interdisciplinary approach is appreciated in the field of biosensor designing. Biomaterials are widely used in biosensing prototypes as polymeric fibers, polymer composites, and conducting materials. Biosensors made from marine biomaterials are biocompatible, thermally stable, and have excellent specificity and selectivity. The significant field of biosensors and the principles of their operation were covered in this study. Varied types of biosensors are available based on biological components, biomaterial types, and transducers. Comparing the sensitivity and effectiveness of sensor systems based on various types of marine biomaterials is very intriguing. Even though there are considerable advances in the field of biomaterials used in biosensors, a lot more remains to be achieved.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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