Chapter

Tapping Significance of Microbial Surfactants as a Biopesticide and Synthetic Pesticide Remediator: An Ecofriendly Approach for Maintaining the Environmental Sustainability

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Abstract

Pests are the major concern for plant infections that affect the agriculture production drastically and result in the loss of economy. Regular use of synthetic chemicals develops resistance in pests and affects soil, plant, and human health. The development and promotion of green technology facilitated by microbiota helps in maintaining a healthy environment. Molecules of microbial origin are well-known elicitors for stimulating and sustaining the plant immune system and fertility level of the soil. They compete with the pathogens for resources like food and space, activate the inherent defenses of plants, synthesize antimicrobial chemicals, or other metabolites that degrade and remediate synthetic chemicals. Biosurfactant (BS) is an important amphiphilic molecule with polar and non-polar. Its structure contributes to its high biodegradability, low toxicity, and stability in harsh environments. In the chapter, the multifunctional properties of biosurfactants, methods used for evaluating their biosurfactant producing abilities, methods used for identification, and characterization of the chemical structure of biosurfactants, along with the significance of metagenomics documented. The mechanisms of biosurfactants in controlling the growth of pests and their importance as pesticide remediations are also discussed.

Keywords: biosurfactants, biocontrol agent, biopesticide, pesticide remediator, metagenomics techniques

1. Introduction

All countries have concern about meeting the expanding food needs, which places an additional burden on the agricultural and food business. Controlling the spread of phytopathogens and raising the soil's fertility level have been top priorities in efforts to increase crop output. To cater to ever-increasing demand,

chemical fertilizers, insecticides, and fungicides are continuously used for decades. Pesticides at the rate of 2 million tons are used annually, with 2% being rodenticides and nematicides and 50% being herbicides, insecticides, and fungicides [1]. These pesticide residues endure in the water and soil for years and develop pesticide resistance among deleterious microbes [2–4]. It has been reported that milk, meat, and other food products contain considerable quantities of pesticide residues [5]. Boedeker with his coworkers highlighted, harmful effects of synthetic chemicals on almost 44% of the farming population every year [6]. The most prevalent morbidities that are connected to these practices include immune system deficits, pulmonary dysfunction, and malignancy [7, 8]. The primary cause of these consequences may be the overuse of agrochemicals, which has been a considerable issue [9]. To enhance soil fertility and prevent insect infestation, it is necessary to consider the revitalization of native soil systems that will resist the use of these synthetic chemical amendments. Finding solutions that hold sustainability in the environment is required urgently. Numerous physical, chemical, and biological strategies are frequently used to solubilize and/or degrade hazardous substances. The use of membrane filtration, adsorption, soil washing, granular activated carbon, and photocatalytic remediation are some of the common examples of physical approaches. Ion-exchange, precipitation, coagulation, floatation, and flocculation procedures are examples of chemical-based methods. These physicochemical techniques that are in use at frequent intervals are relatively futile and unsustainable. Whereas combinations of physicochemical techniques occasionally prosper [10]. It is reported that synthetic surfactants are combined in many pesticide formulations as adjuvants [11]. Synthetic surfactants are expensive, caustic, and impervious to degradation. Hence a green approach that conforms to the strict guidelines of green chemistry and green technology, which are in high demand in the modern period, is essential. It will support to maintain and sustain the desired healthy flora and fauna, which can deliberately keep the ecosystem healthy.

2. Overview of biosurfactants

Surface-active substances known as biosurfactants (BS) are synthesized by some of the prokaryotic and eukaryotic microorganisms in their stationary stage of development. According to a recent survey by Global Market Insight, between 2020 and 2026 year, the BS market is anticipated to expand at a rate of more than 5.5% Compound Annual Growth Rate. In 2019, the market for BS was worth more than USD 1.5 billion [12]. Microorganisms generate BS either extracellularly or as an ingredient of the cell membrane [13, 14]. They are prevalent because of their wide range of benefits against synthetic surfactants (**Figure 1**).

BS nature is highly dependent on the microbial origin and on the available nutrients. In accordance with their chemical complexity or molecular weight, they are categorized as high and low molecular weight BS. Their molecular weights range from 50 to 1500 kDa LWM-BS (Low Molecular Weight Biosurfactants) decrease the surface and interfacial tensions at the air and water boundaries. In disparity, HMW-BS (High Molecular Weight Biosurfactants) also described as "bioemulsans," are efficient at stabilizing the oil in water emulsions (**Table 1**).

Based on the chemical structure, it is an amphiphilic molecule, with a polar head and nonpolar tail. The hydrophilic moiety is made up of intrinsically simple ester, phosphate, hydroxyl, or carboxyl groups, as well as carbohydrates like

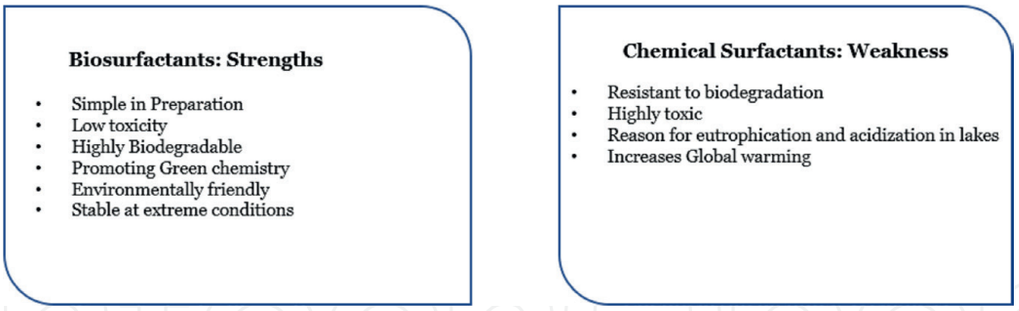

Figure 1.
Biosurfactants strengths and weakness of chemical surfactants.

Biosurfactants	Bioemulsifiers
Low molecular weight-compounds	High molecular weight- compounds
Reduces surface tension and emulsification	The emulsion formed are not stable
Used for stabilization of emulsion	Used for only emulsification
For example-lipopeptides, glycolipids (Rhamnolipids, Sophorolipids, Trehalose lipids, Phospholipids, Corinomiocolic acid, fatty acids), Lipopeptides (Surfactin, Wincnsin, Gramicidin, Substilsin, Peptide lipid, Lichenysin)	For example-polysaccharides, (Emulsan, Biodispersion, Mannan-lipid protein, Carbohydrate lipid-, protein), Particulate (Vesicles)

Table 1.
Differentiating points of biosurfactants and bioemulsifiers.

monosaccharides, oligosaccharides, and polysaccharides, as well as proteins, amino acids, and peptides. Unsaturated or saturated fatty acids, hydroxyl fatty acids, or fatty alcohols make up the hydrophobic portion (**Figure 2**).

Based on its structural characteristics, BS has several advantageous properties which enable them to be employed as an adjuvant or essential component in a wide range of formulations, as a potential bioremediator for synthetic chemicals, and as an emulsifier in an eclectic assortment of industrial applications, such as those involving food and beverage, petroleum, cosmetics, organic chemicals, and

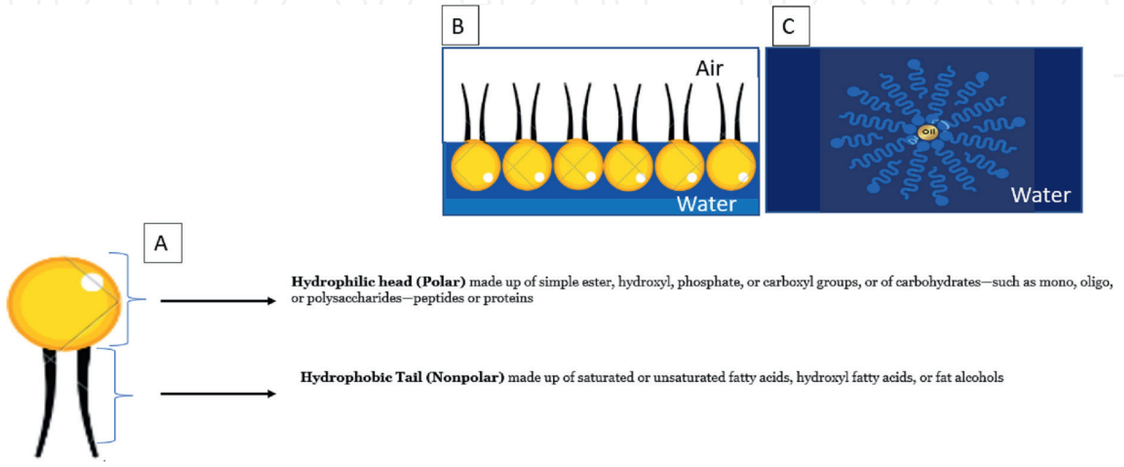

Figure 2.
(A) An amphipathic structure of a biosurfactant, (B) surfactant monomer at the surface of water and (C) micelle formation above CMC (critical micelle concentration).

pharmaceuticals [15]. BS occupies a unique place in the agricultural sector due to its capacity of emulsification, dispersion, solubilization, foaming, and wetting agents, which accelerate hydrophobic molecules' solvation in aqueous media for the formation of emulsion [16–18]. They have proved themselves to be a top contender for leading the way in the field of agricultural and environmental science [19–28].

3. Multifunctional properties of biosurfactants

BSs' amphipathic structure is giving them a special place to showcase their multifunctional properties [16]. A few important multidimensional properties are mentioned in **Figure 3** and detailed description is listed below:

3.1 Surface and interfacial activity

Surface tension is a phenomenon that happens when a liquid surface and another phase come together (it can be a liquid as well). The molecules at a liquid's surface are drawn toward the liquid's center by the contracting force of surface tension. The surface and interfacial tensions of certain fluids can be reduced by BS at extremely low concentrations due to lower Critical Micelle Concentrations (CMC).

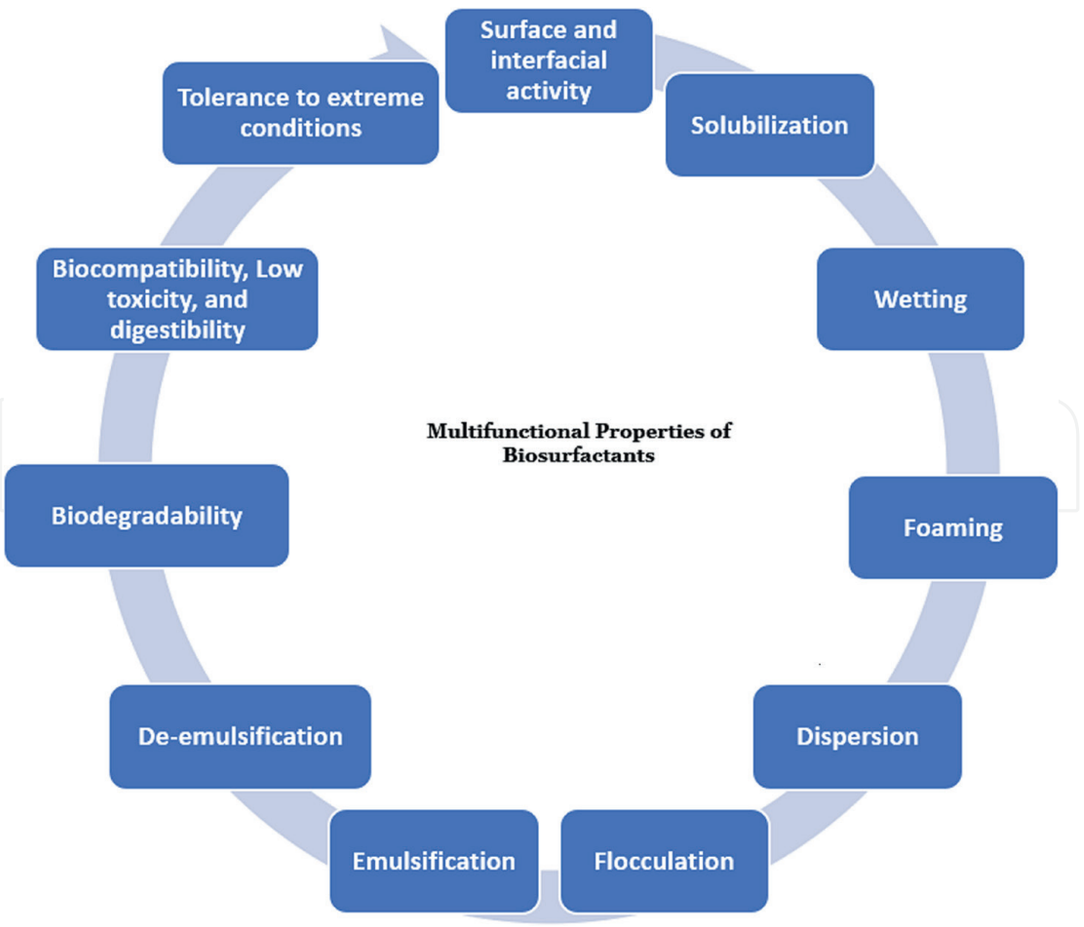

Figure 3.
Functional properties of biosurfactants.

3.2 Solubilization

In the aqueous phase, biosurfactant molecules spontaneously group together and form supramolecular nano sized aggregates with a hydrophobic core and a hydrophilic surface exposed to water. It is formed when BS concentration surpasses a threshold value which is well known as critical micelle concentration—CMC. These small sized aggregations enhance the bioavailability of water-insoluble substances in aqueous liquids or chemical agents by allowing the transportation and confinement of insoluble molecules.

3.3 Wetting

It is the capability of a liquid to provide a link with another surface and to spread out evenly and easily over the top of the surface of another solid or fluid. When a liquid with a high wetting capacity spread across a surface, it creates a thin, continuous film. Biosurfactants are effective wetting agents because they lower liquid surface tension by reducing attractive forces, which enhances affinity toward different surfaces. Instead of connecting them to the surface tension, it penetrates the pores.

3.4 Foaming

Small levels of BS can decrease a liquid's surface tension (lessen the effort required to produce foam) or boost its colloidal stability by preventing bubble coalescence. Biosurfactants are intense at the gas-liquid interface, where they form fizzes that move through the liquid and produce foam. BS is a substance that encourages the production of foam.

3.5 Dispersion

Dispersion results from the decrease in the cohesive attraction between similar particles. A few BS are applied as a dispersion agent to reduce the aggregation of insoluble particles amid each other in the suspension. For example, BS removes hydrophobic molecules from the surfaces of rocks to improve their mobility and recovery in oil extraction steps. Dispersion also plays an additional role to reduce or completely eradicate the biofilm formation of undesirable microbes.

3.6 Flocculation

The process of flocculation starts when colloidal particles, either natively or because of the addition of a clarifying agent, migrate from a condition of suspension to sediment in the form of floc or flake. Emulsions are restored to their original state by these flocs, which can be distorted by mechanical force and aren't permanent.

3.7 Emulsification

It is the process of combining liquids that ordinarily do not mix to create an emulsion. BS has emulsifying and demulsifying properties. The two most prevalent emulsions are water-in-oil (w-0) and oil-in-water (o-w). They are typically unstable in two-phase solutions. Biosurfactants signifies the solubilization of large particles with micellar structures by assisting the dispersion of one liquid into another and making it easier for two immiscible liquids to be mixed.

3.8 De-emulsification

In this process, the stable interface between the internal and bulk levels gets disturbed, due to which the emulsions get split. BS makes the process of de-emulsification easier.

3.9 Biodegradability

BS is a metabolic byproduct of microorganisms and is easily broken down in nature without generating any deleterious byproducts.

3.10 Biocompatibility, low toxicity, and digestibility

They are not harmful or toxic to living tissue. When they are interacting with other organisms, they do not change their bioactivity or mechanism.

3.11 Stability at various extreme conditions

Several BS stay stable across a diversity of adverse environmental situations, such as pH, temperature, and salinity, rendering them potential candidates to be deployed in a comprehensive array of industries.

4. Methods to detect biosurfactants producing ability of a microbial strain

To choose biosurfactant synthesizers from a set of microorganisms, various screening techniques are advocated concurrently (**Figure 4**). A single evaluation system is never recommended [29], various techniques that can be used are:

4.1 Surface tension and interfacial measurement

The aspects of surfaces and interfaces, such as the surface excess concentration, adsorption kinetics, surface pressure, and CMC can be recognized with the aid of tensiometers. These instruments differ in terms of the underlying physical concepts, the mechanical layout, the type of measurements they can perform—static or dynamic—and whether they can detect surface tension (ST), interfacial tension (IM), or both. It is possible to follow the adsorption kinetics by making dynamic measurements on surfaces or interfaces that are not in equilibrium. The most common techniques that are used to evaluate ST, IM or both are Du Noüy ring, Wilhelmy plate, and pendant drop. The strength required to separate a wire ring or loop from a surface or interface is the cornerstone for these strategies. The detachment force and interfacial tension have an inverse relationship. The accuracy, simplicity, and minimal sample volume are needed to make this approach more advantageous. It is the easiest screening technique and is suitable for a preliminary screening.

4.2 Drop collapse method

Polar water molecules are attracted away from the hydrophobic surface in the lack of surfactants, which helps to stabilize the drops. In comparison, when there are surfactants in the liquid, the drops spread or even collapse due to the reduced force

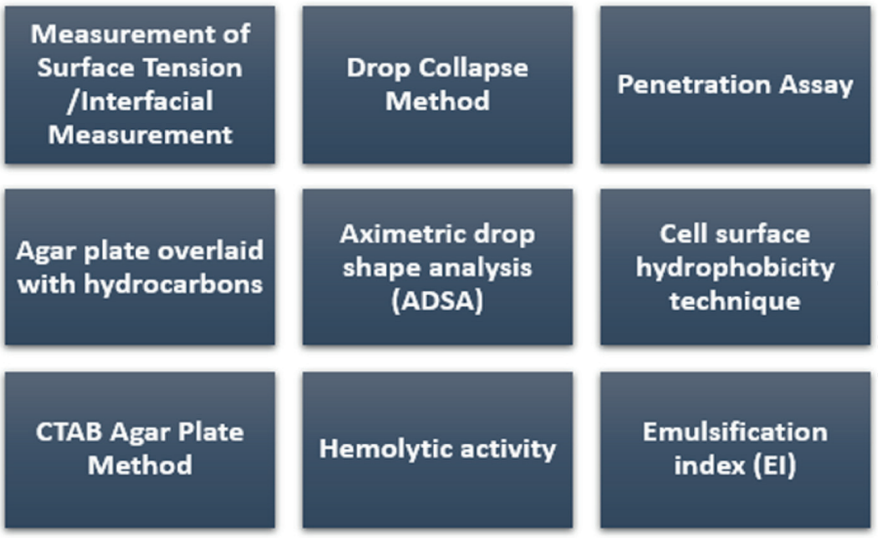

Figure 4.
Methods to detect biosurfactants producing ability of microbes.

or interfacial tension. Drop stability is correlated with surface and interfacial tension and is reliant on surfactant content. It is easy, quick, and simple, and needs a little volume of sample and no specific equipment.

4.3 Penetration assay

This test requires contact between two insoluble phases to function. A staining solution is applied to culture supernatants for easy differentiation. If BS is present, the colored supernatant passes through the oil film barrier and enters the paste. Within 15 min, it transforms the color to murky white. Supernatant devoid of biosurfactants would lose its color when becoming cloudy. It is a quick and effective method to screen through many potential isolates.

4.4 Agar plate overlaid with hydrocarbons

In an oil coated agar plate, an axenic culture is streaked and incubated for 5–7 days at a desired temperature. An emulsified halo around the streaked colonies can be identified as BS producers.

4.5 Aximetric drop shape analysis (ADSA)

The technique includes assessing the drop's shape, which is strongly impacted by the equilibrium between surface tension and outside forces, like gravity. The shape of the drop exemplifies its range of utility and validity.

4.6 Cell surface hydrophobicity technique

It is based on a technique that employs microbes to attach to hydrocarbons. Microorganisms that can actively absorb hydrocarbons typically have highly hydrophobic coverings.

4.7 CTAB (cetyltrimethylammonium bromide) agar plate method

It is used basically to identify their anionic, cationic, nonionic, and neutral nature. The media is supplemented with different dyes such as cetyltrimethylammonium bromide and methylene blue. Presence and absence of a halo zone surrounding the culture reflects its nature and property of the BS.

4.8 Hemolytic activity

In media such as Luria agar (LA) or nutrient agar (NA) fresh blood is mixed. Microbe is streaked and incubated at the desired temperature. After incubation hemolysis zone was observed around the colony which indicates BS synthesizing ability of microbes.

4.9 Emulsification index (EI)

Emulsification activity is calculated by EI. Hydrocarbon is added to the culture broth and mixed. Subsequently allowed to stand overnight. The height of the emulsion formed between aqueous, and hydrocarbon is measured, that defines the stability and strength of a surfactant.

5. Methods to identify and characterize biosurfactants

New approaches are evolving for recognizing and identifying BS because of scientific and technological innovations. The techniques that are used to identify and characterize the BS are as follows (**Figure 5**).

5.1 Thin layer chromatography (TLC)

The most popular, straightforward, and affordable approach for identifying various macromolecules, including carbohydrates, lipids, fats, proteins, amino acids, and peptides. In this methodology, an adsorbent medium such as aluminum oxide (alumina), silica gel, or cellulose is wrapped thinly around a sheet of glass, plastic, or glass. The sample is placed on a plate and given time to go through several mobility phases. The development of the colors after spraying developers helps in recognizing the presence of macromolecules that help in identifying the class and subclass of BS.

5.2 High performance-liquid chromatography (HPLC)

It is the most comprehensive and efficient quantitative tactic. A detector, a mobile phase, and a fixed phase constitute it. The mobile phase moves the sample solution once it is introduced through the injector port. The mobile phase progressively lowers the components of the sample solution over the stationary phase, which is a solid. The migration of the components is regulated by the noncovalent interactions between the compound and the column. This methodology considers several components according to their polarity. The segregated products may then be recognized, and fractions for certain peaks can be obtained to investigate the structure of BS moiety.

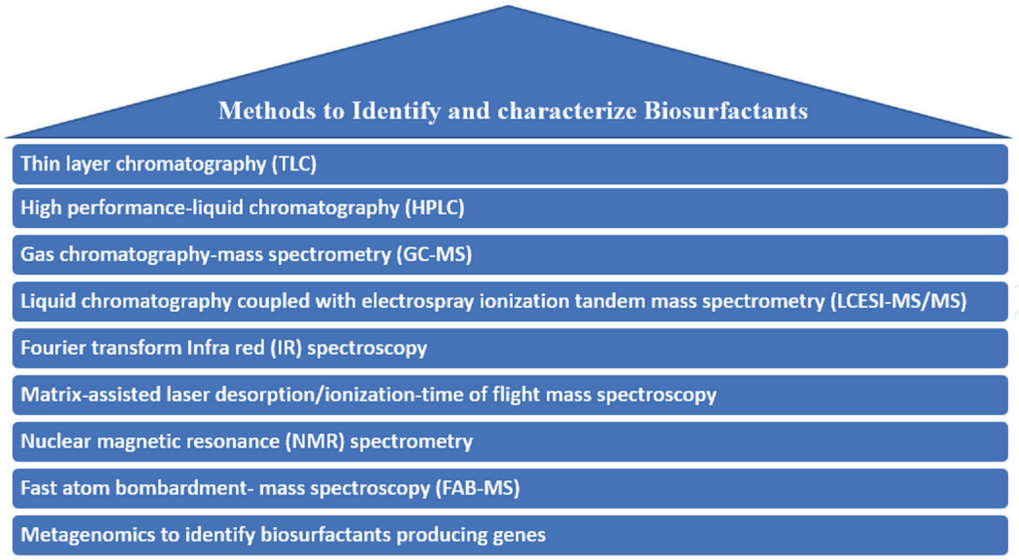

Figure 5.
Methods to identify and characterize biosurfactants.

5.3 Gas chromatography-mass spectrometry (GC-MS)

Mass spectrometry, coupled with either gas or liquid chromatography, is utilized to discover the chemical bonds and structure of BS. In addition, the procedure provides a qualitative and quantitative approach used for detecting the chemical nature of BS. The mass spectrometers are made up of three important components: an ion source, a molecular mass analyzer, and a detector. As a result, volatile samples are directly introduced into the device, whereas non-volatile samples need to be dissolved in volatile solvents. As the sample passes through the electromagnetic field, it immediately becomes ionized. The computer system receives the amplified automated signal and reports it as various chromatogram peaks. It is therefore essential to evaluate the overall quantity and quality of the compounds. The BS compound's hydrophobic component (water-repelling) is typically revealed by GC-MS.

5.4 Liquid chromatography coupled with electro-spray ionization tandem mass spectrometry (LCESI-MS/MS)

The structural makeup of the hydrophilic moiety is revealed by LC-MS (water-loving). Different research centers are currently using these approaches to detect BS biomolecules, which reduces the chance of erroneous characterization. It is defined as a less expensive and less time-consuming procedure and detects BS even at low concentrations.

5.5 Fourier transform infra-red (IR) spectroscopy

It is the most typical type of infrared spectroscopy. According to the underlying hypothesis, some infrared (IR) light is absorbed when it travels through a sample. Molecules with covalent bonds will selectively absorb different wavelengths of light, affecting the bond's vibrational energy. The type of vibration (stretching or bending) depends on the atoms in the linkage. The quantity of radiation that hits the sample is calculated. The spectrum is represented by plotting transmittance and wavenumber (cm^{-1}). It is utilized in the range of around 4000 and 400 cm^{-1}. It detects and

discriminates the spectra between molecules. The sample is not destroyed, and it is substantially faster, more sensitive with an inexpensive strategy.

5.6 Matrix-assisted laser desorption/ionization-time of flight mass spectroscopy (MALDI-TOF)

This method is based on a laser energy-absorbing matrix that creates ions from large molecules with little fragmentation. The MALDI approach is a three-step procedure. The sample is first applied to a metal plate after being blended with a suitable matrix material. After that, the sample is exposed to a pulsed laser, which detects the sample and matrix material. The analyte molecules are then accelerated into a certain mass spectrometer that is being utilized to examine them. After detection, molecules are finally ionized by protonation or deprotonation in the hot plume of gases. Although the process is robust, its reliability is offering its special place in the analytical world. It has been used to analyze molecules like DNA, proteins, peptides, carbohydrates, polymers, and dendrimers that have a propensity to be brittle and fragment when ionized by more conventional ionization techniques.

5.7 Nuclear magnetic resonance (NMR)-spectrometry

It is constructed on transformations that emerge in magnetically significant atoms when an outside magnetic field exists. In a process nucleus absorbs radio frequency radiation, due to which the nuclear spin realigns or splits in the higher-energy direction and emits radiation again and returns the molecule again to the lower-energy state. For each nucleus, the magnetogyric ratio serves as a proportionality factor. NMR can be used to identify the functional groups and linkages within lipid and carbohydrate molecules. The specific location of each functional group and facts about the structural isomers can be revealed by a series of NMR spectroscopy.

5.8 Fast atom bombardment-mass spectroscopy (FAB-MS)

It relies on ionization from the liquid phase, with the probable requirement that the sample molecules congregate at the surface of the liquid matrix in the vacuum. It highlights the BS's lipid structure.

5.9 Metagenomics to identify biosurfactants producing genes

"Metagenomics" is a combination of "meta" and "genomics," which mean "the study of the microbial genome,". In it, microbiota from different environmental samples is identified, and characterized. This technique helps us to explore the sequences of the culturable and unculturable microbial community that can be explored for the betterment [30–32]. The primary processes in metagenomics involve extracting the entire genome, fragmenting the collected DNA with restriction enzymes, and putting it into an appropriate expression vector. It has been established that the gene codes for the proteins and/or enzymes participating in the biosurfactant synthesis pathway [33] are generally aggregated in the region of the chromosome, and the gene cluster is conjured up of between 3000 and 7000 base pairs. There are metagenomic libraries available for biosurfactants, including function-based techniques like Substrate-Induced Gene Expression-(SIGEX) and High-Throughput-(HTP) screening [34–36]. It is reported that the genomic research is integrated with bioinformatics such as phylogenetic

analysis, taxonomic profiling, molecular phylogeny, functional characterization of metagenomes, enzyme research, and system biology studies, including genetic engineering utilizing CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) or Transcription Activator-like Effector Nucleases (TALENs) [37] that enhances structural and functional diversity knowledge about BS. There is a system database known as "BioSurfDB", that has compiled 58 pathways, 96 biosurfactants, 1077 microorganisms, 3736 genes, and 3430 proteins [38]. Genetic engineering techniques, however, only create small or single-gene alterations. To synthesize a good quantity of biosurfactants, more experiments that are based on optimizations are required. New regulatory aspects should be explored, and biosurfactant-producing genes should be transferred to indigenous microorganisms by exploring the importance of CRISPR-based methods [31], that are residing in various habitats which need more attention in the present era.

6. Biosurfactants as biopesticide and their mechanisms

Pests including insects, flies, rats, nematodes, bacterial and fungal infections, and unfavorable plants influence the health, cultivation, and crop yields. Surfactants have considerable structural features because they are employed as adjuvants in the preparation of pesticides to strengthen their efficacy [27]. They are widely used to prevent the growth of the fungus *Aspergillus* species, which causes aflatoxin contamination of crops [39] and to exterminate weed species that reduce land production [40]. On the other hand, its frequent use affects the health of the soil, human, and environment in a drastic manner. The reason for such a cause is its perilous, persistent, recalcitrant, and extended half-life properties. As a result, it is a challenge for researchers and scientists to find an eco-friendly approach to control this harm and pressure on the environment. Green chemistry, which may create highly valuable products and advance green technology, can overcome such problems. By suppressing the proliferation of pests or solubilizing insoluble compounds, the secondary metabolites generated by microorganisms are well recognized for their beneficial aspects on soil and plant health [25, 41, 42]. However, obtaining and using these surfactants from microbes can be a sustainable strategy for maintaining plant, soil, environmental, and human health. There are several biosurfactants derived from microbes that show antimicrobial activity against deleterious microbes that affect plants. As a result, they are proving themselves as promising biocontrol molecules. The various mechanism that highlights the efficiency of BS to be use as biopesticide are as follows:

6.1 Impact on phytopathogens

Antagonistic effects of BS are seen on various plant pathogens such as *Trichophyton rubrum, Colletotrichum gloeosporioides*, *Corynespora cassiicola, Fusarium verticilliodes, Fusarium oxysporum* f. sp. pisi, and [43], *Aspergillus flavus*, *Penicillium roqueforti*, and *Colletotrichum demiatium* [44, 45], *Fusarium graminearum*, *Botrytis cinerea*, and *Podosphaera fusca* [46–48]. *Colletotrichum capsici* [49], *Macrophomina phaseolina* [50], *Fusarium verticillioides*, *Penicillium* sp., and *Aspergillus* sp. [51].

BS inhibits the growth of these pathogens by formation of an antibiofilm layer on various surfaces, which lowers their capacity to connect, structural failure to the intercellular net and conidiophores, and deferred or lacking sporulation, which leads to a reduction in biomass production [52]. BS also causes cellular membrane destabilization, that disrupts the feeding cycle, and eventually, cell rupture leading to lysis [53, 54]. Biosurfactants'

fatty acid components modulate the protein and lipid composition of phytopathogens' cell membranes, altering the osmolarity of the cell and its cell wall structure, and making the pathogens highly receptive to them [55–57]. According to Toral [58] and Hansen [59], BS causes morphological changes in the fungal structure known as hyphae, including swelling of the hyphae, altered mitochondrial organization, lower intracellular pH, esterase activity, and decreased hydrophobicity. BS exhibits more activity against spores [51] than it does against mycelia; this discrepancy in activity may be caused by the differing compositions of mycelia and spores' cell walls [60]. An alternate method to lessen infestations with severe phytopathogens is to strengthen plants' innate immunity that can be seen by BS implementation [61].

6.2 Impact of insects

It represses the short-term attachment of hydroid larvae (*Dynarnena pumila, Obelia loveni* and *Drosophila melanogaster*) and counteracts an attachment and contractility [62–65]. In aphids it damages their cuticle membranes.

7. Biosurfactants and their mechanisms involved in remediating synthetic pesticides

During green revolution, farmers used chemicals such as fertilizers and pesticides (insecticides, herbicides, rodenticides, and fungicides) to satisfy the demand for food. It was noticed only 1% of sprayed pesticides kill their intended target species; the remaining 99 interacts with the soil and produce more complex metabolites that damage the ecosystem and notably the soil quality and human health [66]. Pesticides strongly adsorb organic matter from the soil, preventing it from desorbing. Most pesticides are non-polar chemicals with hydrophobic characteristics that make them water insoluble [67]. The recalcitrant nature of pesticides contributes to a variety of central nervous system problems. In addition to this, pesticides have a huge mutagenic and carcinogenic potential which can result in conditions affecting fertility, skin, and eye problems. It is documented, every year 355,000 persons die from accidental poisonings, which are linked to excessive exposure and inappropriate exposure to dangerous substances [68].

The biodegradation of pesticides by microorganisms through the production of their metabolites has been investigated for the past two decades. Macro and microorganisms use it as it is readily available in ecosystems [18, 69] where many times they consume it as a source of food. When these microbes utilize it, they produce significant metabolites. One characteristic that distinguishes biosurfactants is hydrophilic-lipophilic balance (HLB), which regulates the hydrophilic and hydrophobic constituents balance in surface-active substances [70, 71]. BS is one such prominent metabolite, when present at amounts above CMC, biosurfactant-produced micelles may enhance the solubility and bioavailability of hydrophobic pesticide compounds by lowering interfacial tension and surface tension [72, 73]. Biosurfactant activities rely on the concentration of surface-active molecules until the critical micelle concentration (CMC) is attained. To lower surface tension, efficient biosurfactants have a low CMC and necessitate less biosurfactants [70, 74]. Desorption from soil particles lowers surface tension, facilitating the process of deterioration [75]. One of the most prevalent mechanisms that contribute greatly toward the bioremediation of pesticides by biosurfactants contains counter-ion binding, electrostatic interactions, ion exchange, and precipitation-dissolution [76, 77]. As a result, the soil is made productive, pollution-

free, and fit for agricultural cultivation [78, 79]. A natural, budget-friendly, and environmentally sustainable method of degrading pesticides and other xenobiotics on-site is only possible through microbial biosurfactant-based remediation [18]. Although most research highlights where a single bacterium is used in bioremediation (particularly culturable ones), while only a few reports highlight the use of microbial consortia [72, 80]. The capabilities of biosurfactants to remediate environmental pollutants consequently, the burgeoning environmental safety campaign toward greener technologies are the only concerns of the times [25, 26, 78, 81, 82] that can help goal of European Commission to reduce 50% pesticide pollution by 2030.

8. Conclusion and prospects

To assure the prerequisite of food for a growing population is becoming a big challenge at a global level. Regular use of synthetic chemicals is not always recommendable as they have detrimental impacts on the health of plants, soil, and humans. New strategies to enhance agriculture and food production have appeared in the last decades. Microbes and their metabolites always occupy a special place in all related domains of Biotechnology and allied Sciences. Their stability and diversity always accomplish the goals of sustainability. They also play important role in change in climate action. Among all metabolites reported till date, the multifunctional properties of biosurfactants are making this molecule popular in various domains. Therefore, it is advocated that a cutting-edge notion for evaluating a new, safer, and healthier agricultural and environmental model should be explored more and more.

In the chapter a comprehensive information about various methods employed to identify the biosurfactant ability of the microbe, methods to characterize the chemical structure is discussed. The various mechanisms such as competition, parasitism, antibiosis, induced systemic resistance, and hypovirulence by which BS controls the growth of pests are mentioned. Importance of BS as adjuvants in pesticide formations and their mechanisms in pesticide remediation is described. It is recommended that more attention should be given to this molecule and its mechanisms can be explored for other harmful pests which are not documented to date. Its high stability to varied environmental conditions can be used year-round which highlights its additional advantage in the era where a change in climate is also an immediate concern.

Acknowledgements

SG would like to thank Dr. Vishwanath Karad MIT-World Peace University.

Conflict of interest

The author declares no conflict of interest. The author has contributed to the chapter and agreed for its publication.

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