Bacterial extracellular matrix as a biotechnologically multivalent material source

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ABSTRACT

The Extracellular Matrix (ECM) is a sophisticated megastructure created by bacterial cells to construct architecturally complex biofilms. The ECM's complex chemical makeup reflects its activities of cell protection, modification of cell-to-cell signaling, cell differentiation, and environmental sensing. Proteins, polysaccharides, and eDNA all have different functions, yet they all work together to keep the ECM's architecture and biological relevance. Because of their potential biotechnological uses, from agriculture to the water and food sectors, the gathered information on the chemical heterogeneity and unique capabilities of ECM components has garnered interest. This study combines data on the most important bacterial ECM components, the biophysical and chemical properties that contribute to their biological activities, and their potential for biotechnological uses.

Key Words: *Bacterial biofilms; Extracellular Matrix (ECM); Biotechnology*

INTRODUCTION

The Extracellular Matrix (ECM) is a combination of high-molecular-weight polymers released to the external media by practically all types of cells in both eukaryotes and prokaryotes. The eukaryotic ECM is defined as a non-cellular three-dimensional macromolecular network made up of a variety of components including collagens, proteoglycans/glycosaminoglycan's (PGs), elastin, fibronectin, laminins, and other glycoproteins. This structure is present in tissues and organs, where it provides support for cellular components as well as biochemical and biomechanical signals for tissue morphogenesis, differentiation, and homeostasis. Collagen type I and II, which form massive fibrillar structures when linked with other ECM proteins, collagens, and PGs, are the primary elements of the extracellular matrix of eukaryotic tissues. The 3D matrix network is defined by these structures in conjunction with other ECM molecules. As a result, it's possible that the ECM's content and structure impact biological processes such eukaryotic cell adhesion, migration, proliferation, and differentiation. During morphogenesis, the ECM has been described as a reservoir for the localization and concentration of growth factors and signaling molecules, which generate gradients that are crucial for the formation of developmental patterning. In contrast to eukaryotes, which have cells that are intrinsically grouped to form tissues and organs, bacteria live as independent individuals or form multicellular communities called biofilms that grow on surfaces and provide several benefits such as better adaptation to different environmental conditions, improved attachment to hosts, and improved access to nutrients. Similar to eukaryotic tissues, bacterial cells in biofilms are encased in a secreted and multifunctional ECM that provides i) structural support for the community, ii) improved cellular adhesion, iii) signal and nutrient flux regulation to ensure cell differentiation, and iv) a formidable physicochemical barrier against external assaults. Proteins, exopolysaccharides, nucleic acids, lipids, and secondary metabolites make up the microbial ECM, which all have comparable functions but are chemically different among bacterial species. In this mini-review, we discuss the key components of the prokaryotic ECM, their roles in biofilm development and bacterial interactions with the environment, and the biophysical characteristics that enable their biotechnological use.

Bacterial biofilms are found all over the world and play an important role in changing the environment in a number of ways. However, because bacterial biofilms have been researched extensively with human bacterial pathogens, unfavorable attitudes about contamination and pathogenicity have arisen. Biotechnology research disciplines that benefit from the unique qualities of bacterial biofilms include water, food and agricultural sectors, sustainable agriculture, and the creation of recombinant proteins and compounds. Furthermore, the ability to combine different strains in multispecies biofilms broadens their biotechnological uses, allowing for the creation of a wider range of products than would be achievable with single strain cultures. Adsorption, trapping, and covalent bonding are all methods for immobilizing bacterial biofilms in bioreactors. The most common method in biofilm reactors (fluidized bed reactors, continuous stirred tank reactors, airlift reactors, and packed bed reactors) is adsorption based on cell fixing, and it is probably the most natural method because it takes advantage of bacterial cells' inherent ability to adhere to any given support. Cell immobilization on alginate beads has been effectively employed in the preservation of cell viability, the breakdown and biotransformation of contaminants, and the creation of enzymes, probiotics, and other important products in industrial bioprocesses. The water sector was the first to deploy biofilm reactors for wastewater treatment, including bio filters and moving bed biofilm reactors. Recently, there has been a growth in the creation and application of biofilm-based systems to create a range of important compounds, albeit many procedures must be fully understood to optimize production and get the best yield.

Bacterial biofilms have also demonstrated considerable promise in the food business and the adoption of sustainable agriculture techniques. Biofilms generated by probiotics on the gut epithelium mucosal surface, for example, have proven advantages and health benefits in the food sector. Bacteriocins accumulate in biofilms generated by probiotic bacteria such Lactotoccus reuteri, providing protection against foodborne pathogens. Biofilm-forming bacteria have been proven in the agricultural field to contribute to crop productivity in a variety of ways, including plant growth stimulation and protection from abiotic diseases (dissection or excessive salinity) and microbial infections. Root-colonizing bacteria such as Azotobacter spp., Azospirillum spp., Bacillus spp., Beijerinckia spp., Pseudomonas spp., Rhizobium spp., and Brady rhizobium spp. have been shown to improve plant growth by increasing phosphorus, potassium, and zinc availability, fixing atmospheric di-nitrogen, or triggering the production of hormone Effective colonization and biofilm formation on various plant organs create protective microbial barriers that limit pathogen growth by limiting the availability of essential nutrients and micronutrients for growth and pathogenicity or by producing a variety of antimicrobials. Nanoparticle-entrapped biofilms are being used in new biocontrol tactics to combat bacterial and fungal diseases. This technology has shown encouraging findings, such as the inhibition of Fusarium development by combining ZnO nanoparticles with P. chlororaphis O6, and the enhancement of biocontrol efficacy against maize diseases by combining Nano-silica and Pseudomonas sp.

The usage of bacterial biofilms in soil bioremediation is one of its

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agricultural benefits. Cyanobacteria have been shown to collect large amounts of hazardous chemicals such as pesticides and heavy metals that stay in agricultural soils after treatment. This property may be exploited to immobilize cyanobacteria producing biofilms on alginate and silica gel, enhancing their resistance to harmful chemicals while also providing a number of procedural benefits such as fewer water usage and easier harvesting. Pseudomonas putida and other bacterial species are fascinating from an environmental and industrial standpoint because of their amazing capacity to withstand high concentrations of hazardous chemicals and breakdown contaminants as xenobiotic. Toxic chemical accumulation poses a significant hazard to human health and the environment, and the above-mentioned species are gaining traction as potential microorganisms for bioremediation of polluted soils and streams. Finally, complex multispecies biofilms are of tremendous interest for biotechnological applications because a wide range of microbe combinations can improve bioprocesses through cooperative approaches such as metabolic cross-talk and resource sharing. Degradation of crude oil and desulphurization of dibenzothiophene (DBT) to produce Sulphur-free 2-hydroxybiphenyl are two examples.

Bacterial cells produce a variety of secondary metabolites (lipopeptides, bacteriocins, antibiotics, amino acids, toxins, and so on) during their biofilm lifestyle, which play important roles in the ecology of bacterial communities, either as inhibitors of competitors' growth or as signal molecules that modulate microbial interspecies or inter kingdom communication and behavior. Secondary metabolites' diversity and functions are grounds for their widespread biotechnological interest in a wide range of industries (medical, food industry or agricultural). Secondary metabolites generated by microbial species (daunomycin, mitomycin C, Adriamycin, and others) are used in the treatment of several forms of cancer, as anti-malarial chemicals (gliotoxin), and as antiplasmodials (daunomycin, mitomycin C, Adriamycin, and others) (trichodermol). Furthermore, it is worth noting how different bacterial secondary metabolites contribute to plant health and agricultural productivity by interacting with microbial pathogens: I Small compounds generated by B. amyloliquefaciens, such as bacillaene, difficidin, and macrolactin, suppress Gram-positive and Gram-negative pathogens such as Erwinia amylovora, as well as triggering the plant defense system or promoting plant development. Secondary metabolites are also becoming increasingly popular in the food and flavor sectors. 3-octanone, 1-octen-3-ol, and 3-octanol, generated by Trichoderma spp. in mushroom flavor and fragrance, and the use of probiotics for antioxidant compound synthesis are examples.

CONCLUSION

The ECM is a complex structure with a wide range of chemical and functional properties. Mechanistic research involves increasing our understanding of the chemical structure and biophysical properties of the molecules that make up this structure. Additional research into the characteristics that define the phases of biofilm growth is required to build a strong body of knowledge that will enable polymer modification and even customized design for present and future biotechnological uses. The use of bacterial biofilms or different extracellular matrix components in industrial and agricultural processes is emerging as a very promising strategy, both economically and environmentally, for lowering production costs while increasing productivity, combating pollutants, and serving as an ecological tool against agricultural plagues. Due to the high cost of industrial procedures and the poor yield currently gained from their manufacture, the ability to scale the production of such biotechnological products at an industrial level, and therefore their commercial uses, is a major problem. Studies on the precise genetic regulation of ECM component synthesis, the isolation of novel producer strains, and the use of the best substrates should aid in the selection of the best natural microorganisms, especially when genetic modification is not authorized or economical. Further downstream processes are hampered by the unspecific interaction of some ECM with themselves or medium components. As a result, detailed research on the physicochemical peculiarities of each ECM component are needed to determine the best approaches to optimize extraction and purification processes, as well as how to proceed in the bioreactor, to increase not only yield but also quality and usability of the bio product.