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Application of Biofilm in Plant Rhizosphere for Sustainable Agriculture

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Abstract- Soil environments are productive and the plant rhizosphere shelters a remarkable diversity of microorganisms that exchange signals and beneficial nutrients. Biofilms play an essential role in colonizing soil surfaces, roots or shoots of plants and enable expansion in the desired areas, besides enhancing soil fertility. Biofilm formation is considered a natural aspect of bacterial growth, and the bacterial cell is found universally on natural or artificial surfaces in both biotic and abiotic conditions. Bacterial biofilm configuration expands from unicellular to multicellular and creates a heterogeneous arrangement of cells. There are several reports related to the advantageous use of these biofilms. Favourable biofilms could be used for a wide variety of applications in the agricultural field. In agriculture, plant growth-promoting rhizobacteria (PGPRs) enhance plant growth in addition to quorum sensing in the mode of biofilm. Antibiotics produced by PGPRs act as biocontrol agents. In a successful plant-microbe interaction, plant-root colonization by PGPR is attributed in addition to biofilm formation against microbial pathogens. The agricultural industry may primarily benefit from biofilms in terms of their biochemical, fermentative, antimicrobial and biotechnological characteristics. Biofilms also have importance in the water and soil safety of agricultural land. Understanding the factors and genes involved in biofilm formation will help develop more effective strategies for sustainable and environment-friendly agriculture. In this review paper, we have discussed such applications of biofilms in agriculture.

Keywords: Biofilm, Agriculture, Bacteria, Environment friendly, Secondary metabolites, Rhizobacteria

I. INTRODUCTION

The rhizosphere is a centre of microbial communications which influences plant functioning. The rhizosphere comprises the ectorhizosphere, endorhizosphere and the rhizoplane layers, each colonized by several microbial groups. They can exist independently as single-celled, consortia or biofilms. Understanding such agriculturally relevant biofilms in more detail will shed more light on their implications on bioremediation, improving plant nutrition, plant protection and soil fertility. For the plant, the metabolic processes are greatly influenced by the microbial community present in the rhizosphere and their interactions as community/biofilm assemblages [1].

Plant growth-promoting rhizobacteria (PGPR) mediated plant-root settlement is correlated with biofilm development against microbial pathogens in a strong plant-rhizosphere interaction. *Pseudomonas fluorescens, Bacillus subtilis, Pseudomonas aeruginosa* and*Paenibacilluspolymyxa* from a biofilm and a multicellular growth model likely prevails in nature a shielding tool toward hostile environmental conditions [1].

There is a need to explore the mechanisms involved, the association's particular role, and the importance that could unhitch the applicability of such bacterial biofilms in sustainable agriculture and improvement of crop potency.

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II. CONCEPT OF BIOFIMS

Biofilms are self-organizing, primarily sessile, autonomously replicating microbial communities embedded in a self-produced and environmentally enhanced extracellular matrix, which resembles the tissue structure of higher organisms. The self-organization of self-replicating microbes is administered by extremely conserved as well as organism-specific developmental applications. Bacteria and fungi, but even viruses, protozoa, and other free-living organisms, can arrange in biofilms individually and in combination [2].

Biofilms can be single or multi-layered with various microbes within the matrix correlated with a distinct surface. Bacterial biofilms have been analysed in detail because they have characteristics that enable their use in multiple applications in agriculture. Biofilms have been found to break down compounds containing complex nutrients. They can trap pathogens from contaminated water before releasing them into the environment or utilization for agriculture purposes. Multiple experiments have been conducted on biofilm associations with biotic surfaces, and this provided us with a purpose for the use of bacterial biofilms in agriculture [2].

III. EXTERNAL FACTORS INFLUENCING BIOFILM FORMATION

Various microbial products can impact the process of biofilm formation.The function of cyanide synthesis has been described in pseudomonas virulence affecting plant root growth and other rhizospheric methods [5]. This inhibits the initial growth of the root due to the destruction of an auxin-responsive gene, especially at the root tip by *pseudomonas cyanogenesis*. Other helpful rhizospheric processes are also influenced by *Pseudomonascyanogenesis, like Bacillus subtilis* colonization by biofilm production on *A. thaliana* Col-0 roots. The result of cyanogenesis on *Bacillus subtilis* biofilm formation was additionally established by the downregulation of major *B. subtilis* biofilm operons epsA and yqxM. [2,5].
Several agents in laboratories and soil environments are recognized to control the survival, growth, activities of microorganisms and root colonization. These are presented by microbial physiology and cell structure, quorum sensing interference, synthesis of exopolysaccharides, the impact of plant root and root exudates, interaction with another microorganism, and Physico-chemical characteristics of soil and organic matter in the soil [3]. In the rhizosphere, plant roots communicate both beneficial and pathogenic bacterial intercommunications. The metabolite generation in some classes of bacteria improves root growth and other root–microbe cooperations in the rhizosphere [4].

IV. BIOFILMS IN NATURE AND THEIR MATRIX

Bacterial cells were recognized and distinguished as free-living cells, but under different environmental conditions, they exist as biofilms [7]. The development and dispersal of biofilm are well defined and known to involve the following steps: intercellular attachment, initial attachment, desorption, biofilm dispersion and biofilm maturation [8]. Biofilm structures are complex, consisting of large cell densities of 108–1011 cells per gram wet weight, and the matrix estimates for over 90% dry weight while the micro-organism dry weight contributes <10% [9]. Bacterial biofilms can be categorized based on their diversity, ranging from simple to complex clustered film to featureless and maintain various physiological properties [10]. The properties of biofilm communities are different from the free-living bacterial cells due to a self-produced matrix [11].

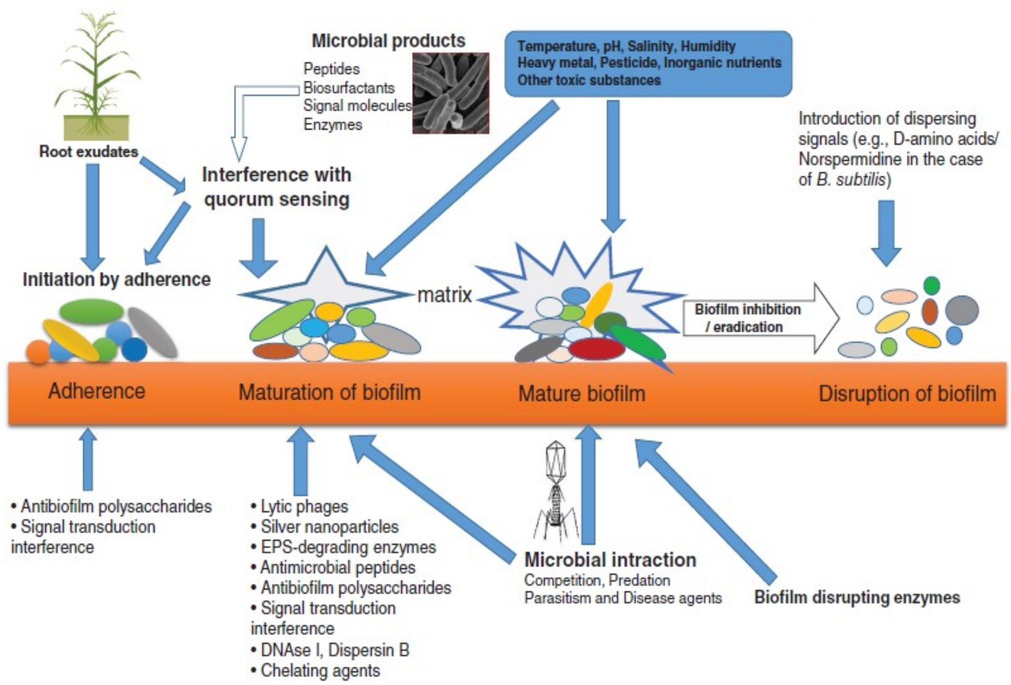

Fig1: Effect of various factors on biofilm formation/disruption *in vitro* and in the rhizosphere [6].

Source:Ansari, Firoz & Jafri, Huma & Ahmad, Iqbal &Abulreesh, Hussein. (2017). Factors Affecting Biofilm Formation in in vitro and in the Rhizosphere. 10.1002/9781119246329.ch15.

V. BIOFILMS IN PLANT-ASSOCIATED COLONIES

The rhizosphere is regulated by the plant roots and their fluids released in the soil, and bacteria colonize them via the emigration from bulk soil to the rhizoplane. The association and prosperous establishment of rhizobacteria to plant roots rely on the cell adhesiveness and production of microcolonies.

Many beneficial interactions have been studied between plant root surfaces and micro-organisms (*Pseudomonas*, *Burkholderia*, *Bacillus* and *Paenibacillus)* [12,13](Table 1). The biofilm formation on plant roots may also be inducted by signals such as nutrient and water availability and bacteria–bacteria interactions and formed under stressed conditions [14]. The features of the root surface change along the length of the roots, and biofilm formation is influenced by the nutrients and fluids released by the roots at different sites. The cell division and root cap zone are notable sites for bacterial colonization compared to the less colonized mature root zone and hairs [15].

Bacterial strain	Experimental host plant	Functional traits	Observed under natural/controlled conditions	Reference
Proteus sp., *Pseudomona* sp., *Ensifermeliloti* (metal-polluted soil)	Alfalfa	Remediation of metal-contaminated soils	Controlled conditions	[24]
Pseudomonas sp. (sewage sludge)	Rice	Bioremediation of phenanthrene	Controlled conditions	[25]
Pseudomonas entomophila (rhizoplane of wheat)	Wheat	Tolerance to abiotic stress	Controlled conditions	[26]
Bacillus subtilis (rhizoplane)	Arabidopsis	Biocontrol	Controlled conditions	[27]
Pseudomonas putida (roots of chickpea) *and Bacillus amyloliquefaciens* (alkaline soil)	Chickpea	Synergistic growth enhances the plant-growth-promoting attributes	Natural and Controlled conditions	[28]
Azospirillumbrasilense (rhizosphere of sorghum)	Sorghum	Enhance NO and indole-3-acetic acid	Controlled conditions	[29]

Table 1: Beneficial bacterial biofilm associated with plant roots [2].

This table does not describe complete details of Beneficial bacterial biofilm associated with plant roots. For more details check: Pandit, A., Adholeya, A., Cahill, D., Brau, L. and Kochar, M. (2020), Microbial biofilms in nature: unlocking their potential for agricultural applications. J Appl Microbiol, 129: 199-211.

VI. FUNCTIONS OF BIOFILMSIN AGRICULTURE BIOTECHNOLOGY

Biofilms grown in the soil rhizosphere are a hotspot for intercommunication between inter-kingdom associations, shaping the microbial assemblages [16]. Concentrating on the agriculture sector, biofertilizer biofilms can have good advantages (Fig. **2**). These eco-friendly products have the potential to overcome the drawbacks of traditional chemical-based fertilizers.

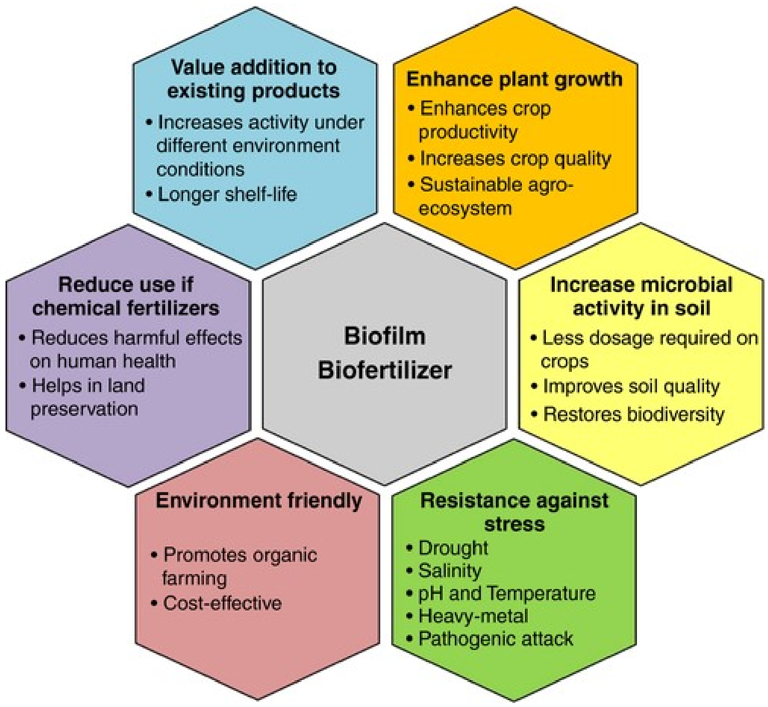

Figure 2: Snapshot of the benefits and applications of the biofilm biofertilizer [2].

Source:https://sfamjournals.onlinelibrary.wiley.com/cms/asset/3132c918-3073-4a91-8590-e8a94244d279/jam14609-fig-0003-m.jpg

Such products may guard the plant against the various environmental and soil-borne illnesses but also against abiotic forces like drought, salinity, organic and inorganic pollutants, potentially increasing crop productivity [17]. Biofilms in the rhizosphere may also help improve water stability and microbial biomass, encouraging the root fluid response under pressure [18]. Biodegradation of organic pollutants and heavy metals can be done using biofilms, as such arrangements can easily withstand severe environments due to the matrix [19]. They can be applied as useful bacterial biofilm inoculum or as mixed inoculum straight to the plants as sprays on the aerial parts or like inoculum in the soil to improve plant growth [20].

The plant-microbe interactions that occur in mycorrhized plants can also help increase mycorrhization and directly affect the diversity of the microbial community in its surroundings[22]. Thus, plant growth profits from such interactions, and the soil quality improves with increased nutrient cycling [23]. The enhanced focus must also be on multiple-species biofilms, producing polysaccharides and bioactive compounds with more notable positive influences on plant growth and soil fertility.

VII. CONCLUSION

Bacterial biofilm formation mostly depends on the properties of bacterial strains and other external factors. Bacteria are majorly known to produce biofilm under natural conditions. Standard properties of bacteria accountable for biofilm formation include specific adhesins, expression of various genetic products such as EPS, regulation and switching capability and quorum sensing from sessile to planktonic and vice versa. More researches are needed to obtain standard results of biofilm-associated organisms *in vitro* and in field conditions. The major challenge in the study of biofertilizer biofilms lies in identifying and selecting potential strains with essential properties to lead to novel outcomes for future sustainable agriculture and efficient agricultural systems.

REFERENCES

[1] Rafique, M., Hayat, K., Mukhtar, T., Amna, Aa, K., Ms, A., Hussain, T., Sultan, T., Mfh, M., Imran, M., &Hj, C. (2015). Bacterial biofilm formation and its role against agricultural pathogens.

[2] Pandit, A., Adholeya, A., Cahill, D., Brau, L. and Kochar, M. (2020), Microbial biofilms in nature: unlocking their potential for agricultural applications. J Appl Microbiol, 129: 199-211.

[3] S. Haldar and S. Sengupta, Plant-microbe Cross-talk in the Rhizosphere: Insight and Biotechnological Potential, *The Open Microbiology Journal*, 9, 1–7 (2015).

[4] T. Rudrappa, M.L. Biedrzycki, H.P. Bais, Causes and consequences of plant-associated biofilms. *FEMS Microbiol Ecol*, 64, 153–166. (2008).

[5] T. Rudrappa, Cyanogenic *Pseudomonads* Influence Multitrophic Interactions in the Rhizosphere, *PLoS ONE*, 4, 2073 (2008).

[6] Ansari, Firoz & Jafri, Huma & Ahmad, Iqbal &Abulreesh, Hussein. (2017). Factors Affecting Biofilm Formation in in vitro and in the Rhizosphere. 10.1002/9781119246329.ch15.

[7] Omar, A., Wright, J.B., Schultz, G., Burrell, R. and Nadworny, P. (2017) Microbial biofilms and chronic wounds. *Microorganisms* **5**,

[8] Achinas, S., Charalampogiannis, N. and Euverink, G.J.W. (2019) A brief recap of microbial adhesion and biofilms. *Appl Sci* **9**, 2801.

[9] Flemming, H.C., Wingender, J., Szewzyk, U., Steinberg, P., Rice, S.A. and Kjelleberg, S. (2016) Biofilms: an emergent form of bacterial life. *Nat Rev Microbiol* **14**, 563–575.

[10] Koo, H., Allan, R.N., Howlin, R.P., Stoodley, P. and Hall-Stoodley, L. (2017) Targeting microbial biofilms: current and prospective therapeutic strategies. *Nat Rev Microbiol* **15**, 740–755.

[11] Berlanga, M. and Guerrer, R. (2016) Living together in biofilms: the microbial cell factory and its biotechnological implications. *Microb Cell Fact* **15**, 165.

[12] Vardharajula, S., Ali, S., Grover, M., Reddy, G. and Venkateswarlu, B. (2011) Drought-tolerant plant growth promoting *Bacillus* spp.: effect on growth, osmolytes, and antioxidant status of maize under drought stress. J Plant Interact 6, 1–14.

[13] Jung, B.K., Hong, S.J., Park, G.S., Kim, M.C. and Shin, J.H. (2018) Isolation of *Burkholderiacepacia* JBK9 with plant growth-promoting activity while producing pyrrolnitrin antagonistic to plant fungal diseases. Appl Biol Chem 61, 173–180.

[14] Zúñiga, A., Donoso, R.A., Ruiz, D., Ruz, G.A. and González, B. (2017) Quorum-sensing systems in the plant growth-promoting bacterium *Paraburkholderiaphytofirmans* PsJN exhibit cross-regulation and are involved in biofilm formation. Mol Plant Microbe Interact 30, 557–565.

[15] Timmusk, S., Grantcharova, N. and Wagner, E.G.H. (2005) *Paenibacilluspolymyxa* invades plant roots and forms biofilms. Appl Environ Microbiol 71, 7292–7300.

[16] Hassani, M.A., Durán, P. and Hacquard, S. (2018) Microbial interactions within the plant holobiont. Microbiome 6,

[17] Malusá, E., Sas-Paszt, L. and Ciesielska, J. (2012) Technologies for beneficial microorganisms inocula used as biofertilizers. Sci World J 2012,

[18] Kasim, W.A., Gaafar, R.M., Abou-Ali, R.M., Omar, M.N. and Hewait, H.M. (2016) Effect of biofilm forming plant growth promoting rhizobacteria on salinity tolerance in barley. Ann Agric Sci 61, 217–227.

[19] Gkorezis, P., Daghio, M., Franzetti, A., Hamme, J.D.V., Sillen, W. and Vangronsveld, J. (2016) The interaction between plants and bacteria in the remediation of petroleum hydrocarbons: an environmental perspective. Front Microbiol 7,

[20] Hettiarachchi, R.P., Dharmakeerthi, R.S., Jayakody, A.N., Seneviratne, G., de Silva, E., Gunathilake, T. and Thewarapperuma, A. (2014) Effectiveness of fungal bacterial interactions as biofilmed biofertilizers on enhancement of root growth of *Hevea* seedlings. J Environ Prof Sri Lanka 3, 25–40.

[21] Deveau, A., Bonito, G., Uehling, J., Paoletti, M., Becker, M., Bindschedler, S., Hacquard, S., Hervé, V. *et al*. (2018) Bacterial–fungal interactions: ecology, mechanisms and challenges. FEMS Microbiol Rev 42, 335–352.

[22] Gui, H., Purahong, W., Hyde, K.D., Xu, J. and Mortimer, P.E. (2017) The arbuscular mycorrhizal fungus *Funneliformismosseae* alters bacterial communities in subtropical forest soils during litter decomposition. Front Microbiol 8.

[23] Velmourougane, K., Prasanna, R. and Saxena, A.K. (2017) Agriculturally important microbial biofilms: present status and future prospects. J Basic Microbiol 57, 548–573.

[24] Raklami, A., Oufdou, K., Tahiri, A.I., Mateos-Naranjo, E., Navarro-Torre, S., Rodríguez-Llorente, I.D., Meddich, A., Redondo-Gómez, S. et al. (2019) Safe cultivation of Medicago sativa in metal-polluted soils from semi-arid regions assisted by heat- and metallo-resistant PGPR. Microorganisms 7.

[25] Zhou, Y. and Gao, X. (2019) Characterization of biofilm formed by phenanthrene-degrading bacteria on rice root surfaces for reduction of PAH contamination in rice. Int J Environ Res Public Health 16.

[26] Ansari, F.A. and Ahmad, I. (2018) Biofilm development, plant growth promoting traits and rhizosphere colonization by Pseudomonas entomophila FAP1: a promising PGPR. Adv Microbiol 8, 235–251.

[27] Dwivedi, D., Khare, M., Chaturvedi, H. and Singh, V. (2017) Plant pathogenic bacteria: role of quorum sensing and biofilm in disease development. In Biofilms in Plant and Soil Health ed. Ahmad, I. and Husain, F.M. pp. 387–407. Hoboken, NJ: Wiley-Blackwell.

[28] Kumar, M., Mishra, S., Dixit, V., Kumar, M., Agarwal, L., Chauhan, P.S. and Nautiyal, C.S. (2016) Synergistic effect of Pseudomonas putida and Bacillus amyloliquefaciens ameliorates drought stress in chickpea (Cicer arietinum L.). Plant Signal Behav 11, e1071004.

[29] Koul, V., Tripathi, C., Adholeya, A. and Kochar, M. (2015) Nitric oxide metabolism and indole acetic acid biosynthesis cross-talk in Azospirillumbrasilense SM. Res Microbiol 166, 174.