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Exopolysaccharides from Cyanobacteria: Potential Source, Extraction Process and Application: A Review

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Abstract: Cyanobacteria are photosynthetic prokaryotic organisms and they can be unicellular or filamentous. They are well known to secrete exopolysaccharides and other bioactive compounds. Exopolysaccharide from Cyanobacteria are not fully explored in spite their important biological and physiochemical properties. Currently the focus of interest of scientific community is shifting towards developing the specific culture and improved downstream processes and increasing the knowledge that can lead led to the extraction of high value bioactive compounds. The aim of this review is to organize the available literature and information about the various application and utility of cyanobacterial exopolysaccharides.

Keywords: Bioactive compounds, Bio flocculants, Bioprocess, Cyanobacteria, Exopolysaccharides

Introduction

Polysaccharide, the carbohydrates that have been used in various industries as raw material, hydrocollids, biological agent and bio sourced materials (Cruz et al., 2020). These biopolymer could be obtained from animals, plants, fungi, seaweeds and microbes including microalgae and cyanobacteria (Kant et al., 2022, Torres et al., 2019). Biologically they are synthesized by entrapping carbon via photosynthesis and some organic pathways. They are the complex biomolecule having high molecular weight formed by the glycosidic bonds (Thakur, 2017). Glycogen (from Animal), Chitin (from Fungi) cellulose, starch, gum and resins (from plant source) are some of the most well-known, and traditionally utilized polysaccharide (Navarro et al., 2019). In case of cyanobacteria it is mainly obtained as Exopolysaccharide (EPS) (Delattre et al., 2016). At present there is no clear classification of EPS in cyanobacteria but many researcher scholars classified EPS into two types based on their location: one is Cell bound Polysaccharide which comprises sheath, capsule and slime layer in cyanobacteria another one is Released Polysaccharides (RPS) i.e. excreted into the surrounding.

Cyanobacteria (Blue-green Algae) are the photosynthetic prokaryotic microorganisms that can be unicellular or filamentous and they exhibits a range of variations in their cellular structures and bioactive compounds in response to changing environmental conditions of their habitat(Kant et al., 2004a-c 2020; Neha et al., 2021; Doli et al., 2023; Sarma et al., 2024). They are also characterized by their rapid growth rates, widespread distribution (Kumar and Kant, 2023; Sarma et al., 2022) and effective abilities to fix nitrogen (Pandey et al., 2008; Kant et al., 2006a-b). Cyanobacteria are unique prokaryotes that could perform Oxygenic photosynthesis, also generate biofuels, high biomass, and bioremediation of wastewater (Singh et al., 2022a-b, 2023).They are well known to secrete exopolysaccharides and other bioactive compounds (Kant et al., 2005, 2008a-b). Secretion of EPS to cope with the adverse environmental factors is one of the main characteristic features of these microorganisms (Kant et al 2005). EPS are secreted outside the cell and they form sheath like layer around their cells. EPS are known to protect the cell in stressed condition like desiccation, radiation and rising temperature.

Cyanobacterial EPSs exhibit two typical features that distinguish them from the polymers synthesized by other bacteria: (1) more than 90% of the so far characterized EPSs show a strong anionic character due to the presence of one or two different uronic acids; (2) they are complex heteropolysaccharides, about 75% of them having shown the presence of six or more different types of monosaccharides(Pereira et al., 2009). Cyanobacterial EPSs has been reported to be a good source of organic biostimulant for crop growth. They provide the protection and improve the response against the biotic as well as abiotic stress. They also promote the solubilization, Mineralization and bioavailability of Macro-Micronutrients to the plants thus improving the crop performance. Sulphated polysaccharide that is obtained from Porphyridium which is red marine algae helps in wheat crop. It is comparable to the commercially used Hoagland solution and $MgCl_2$ (Tiwari, et al., 2022).

In recent years, attention towards the valuable polysaccharides producing strains of cyanobacteria has been increased due to various industrial application. Strains those produce capsule slime and release a significant amount of EPS are preferred (Sutherland, 1988). In most of the cyanobacterial polysaccharide, Uronic subunits are found to be more abundant (De Philippis &Vincenzini,1988) and due to the presence of carboxyl groups could efficiently associated with the metal ions. Thus, the potential of EPS obtained from cyanobacterial strains to trap metal ions would be quite promising. Many studiesindicates one of the important function of sulfated EPS in cyanobacteria is keeping the cell aggregates together in blooms of cyanobacteria and nutrient storage (Strieth et al.,2021) though not much is known about the synthesis of these cyanobacterial polysaccharide and about their natural role. Figure 1 shows some cyanobacterial strains forming EPS in nature and culture condition.

Exopolysaccharide

Analysing the molecular composition of EPS by using modern techniques of chromatography and mass spectrometryrevels that Glucose (Glc), Fructose (Fruc), Galactose (Gal), Arbinose (Ara), Mannose (Man), Xylose(Xyl), ortho-methyl sugar (o-MS)and residues of Galacturonic acid (Gal-UA) and Gluc-uronic acid (Glc-UA) are some of the principle units of EPS.EPS biofilms serves as a protective covering, a means of storing nutrients, and keeps the cells together. EPS is primarily composed of water, polysaccharides, proteins, lipids, and nucleic acids, as well as lysis and hydrolysis products, making the structure extremely complicated (Strieth et al, 2021). Cyanobacterial EPS generally exhibit an anionic nature essentially due to their high uronic acid concentration (Parikhand Madamwar 2006).

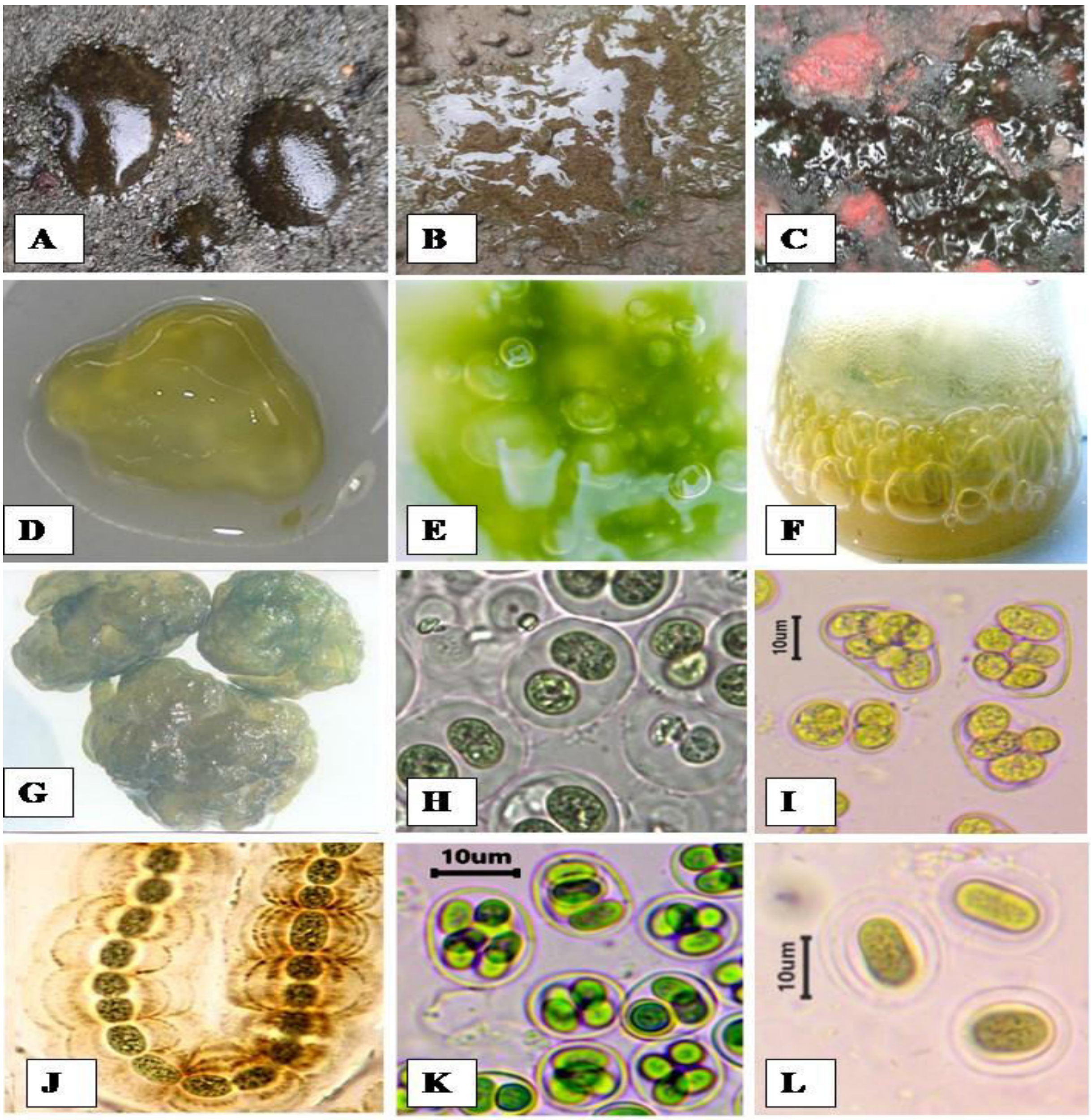


Figure-1. Plate **A-C** :Aphanothece sp. forming gelatinous sheath of exopolysacharride in Nature; **D,G:**Aphanothece spand **E-F**: Gleothece sp. in culture condition; **H, I,K,L** are Aphanothece sp. and **J**-Nostoc sp. enclosed in Exopolysaccaride Sheath (Scale bar= 10μm).

Table-1 Shows some of the exopolysaccharides obtained from cyanobacterial strains:

S.NO	Species name	Monomeric Subunits	Other compound	References
I. Coccoid cyanobacteria				
1.	Chroococcus minutus SAG B 41.79	Glc*, Man, Xyl, Ara, 4MS	AA	Adhikary et al., 1986
2.	C.submarines strain BM	Rha, Fuc, Xyl*, Glc, Gal, Man	UA, sulphate	Rechter et al., 2006
3.	Cyanothece 16Som2	Gal, Glc*, Man, Xyl, Fuc, Rha	UA	De Philippis et al., 1998
4.	Cyanothece CA3	Glc, Man, Ara*, Fuc, Rha	UA	De Philippis et al., 1998
5.	Cyanothece CE9	Gal, Glc*, Man, Fuc, Rha	UA	De Philippis et al., 1998
6.	Cyanothece ET2	Gal, Glc, Man Ara*, Fuc, Rha	UA	De Philippis et al., 1998
7.	Cyanothece IR20	Gal, Glc, Man, Rib, Fuc, Rha*	UA	De Philippis et al., 1998
8.	Cyanothece sp. ATCC 51142	Rib, Xyl, Glc*	AA	Parikh et al., 2006
9.	Gleothece PCC 6501	Gal*, Glc, Man, Rha, Xyl,1MS	UA, AA	Weckesser et al., 1987
10.	Johannesbaptistia pellucida strain GC	Ara, Rha, Fuc, Xyl, Glc, Gal, Man	UA, sulphate	Rechter et al., 2006
11.	Microcystis flos-aquae C3-40	Gal, Glc, Man*, Rha, Xyl	-	Plude et al., 1991
12	Rhabdoderma rubrum CH	Fuc, Xyl*, Glc, Gal, Man	UA, sulphate	Rechter et al., 2006
II. Non-heterocystous Filamentous cyanobacteria				
13.	Arthrospira platensis	Fucose , Fruc,,Gal, Glc*, Man, Rha, Rib, Xyl	UA	Sakamoto et al., 2011
14.	Lyngbya confervoides S 9 g	Gal, Glc , Man, Rha, Xyl, Ara, Fuc	-	Gloaguen et al 1995
15.	Microcoleus vaginatus	Ara, Rha, Fuc, Xyl, Man*, Gal,	UA,MS	Hokputsa

		Glc		et al., 2003
16.	M. vaginatus	Rha, Xyl, Man, Gal, Glc*	AA	Sakamoto et al., 2011
17.	Oscillaria sp.	Glc*, Xyl, Rib	AA	Parikh et al., 2006
18	O. amphibian PCC 7105	Gal, Glc , Man, Rha, Xyl, Fuc	-	Gloaguen et al., 1995
19.	O. corallinae CJ 1	Gal, Glc*, Man, Rha, Xyl, Fuc	UA, sulphate	Gloaguen et al., 1995
20.	Phormidium ectocarpi N 182, K5, ME3, C86, PCC 7375	Gal, Glc*, Man, Rha, Xyl, Fuc	UA	Gloaguen et al., 1995
21.	P. foveolarum MEU, C52	Gal, Glc, Man, Ara±, Fuc, Rha, Xyl, Rib±	UA, AS±, sulphate	Gloaguen et al., 1995
22.	Phormidium sp. PNG 91, 90-14/1,CCAP 1464/3	Gal, Glc, Man, Rha, Xyl, Ar, Fuc, Rib	-	Gloaguen et al., 1995
23.	P. tenue	Ara, Rha, Fuc, Xyl, Man, Gal, Glc	-	Hu et al., 2003
24.	P. battersii strain GF	Ara, Fuc,Xyl,Glc, Gal Man	-	Rechter et al., 2006
III. Heterocystous Filamentous Cyanobacteria				
25.	Anabaena Cylindrica	Gal, Glc*, Man, Xyl, Fuc	-	Dunn et al.. 1970
26.	Calothrix Paritena	Gal, Glc*, Man, Rha, Ara, Xyl, Fuc, MS	UA, AA, As	Weckesser et al., 1988
27.	Fischerella PCC 7414	Gal, Glc*, Man, Xyl, Fuc, 1MS	UA, AA, As, sulphate	Pritzer et al., 1989
28.	Mastigocladus laminosus	Rha, Fuc, Xyl, Man, Gal, Glc	-	Gloaguen et al., 1999
29.	Nostoc carneum	Man* ,Xyl,	-	Parikh et al., 2006
30.	Nostoc IARI 221	Gal, Glc*, Man, Rha, Xyl, Ara	UA	Mehta et al., 1978
31.	Nostoc sp.	Rha, Xyl, Man, Gal, Glc	-	Hokputsa et al., 2003
32.	N. verrucosum	Xyl, , Glc*,Man*	UA	Trabelsi et al., 2016
33.	N. insulare	Glc	UA, MS, AA	Volk et al., 2007

34.	Scytonema javanicum	Ara, Rha, Xyl, Man, Gal, Glc*	-	Hokputsa et al., 2003

Glc-Glucose; Fruc-Fructose; Xyl-xylose; Gal-Galactose; Man- Manose; Rib- Ribulose; Rha-Rhamnose ; Ara-Arabinose ;(*)-Major subunit; UA-Uronic acids; MS- methyl sugars; AA-Amino sugar.

There is substantial negative charges on external cell layer of cyanobacteria due to the EPS formation, thus they can be utilized as a effective chelating agents for the separation of heavy metal ions from aqueous environment (De Philippis and Micheletti, 2009). sulphur containg EPS in is known to keep the cell aggregates together in cyanobacterial bloom, though very little is known about the synthesis of cyanobacterial exopolysaccharides. Maeda et al. (2021), observed few cyanobacterial strains that causes the bloom like aggregates which were enclosed in sulfate containing EPS. Researchers able to identify a certain types of genes that are associated with the synthesis and regulation of Sulfated-EPS, It is also reported that the cell aggregates in cyanobacteria can float despite the absence of gas vesicles, which is usually the reason of blooms floating.

EPS Applications:

Cyanobacterial based EPS having huge ecological and commercial potential. Possible application of cyanobacterial EPS are given in Figure-2.

Bioactivity

1. Anti-oxidant activity and anti-bacterial activity

Various Cyanobacterial EPS have been reported to have dose dependent antioxidant potential i.e scavenging activity on radicals (superoxide, peroxide and hydroxyl radical) like Spirulina platensis Nostoc Carneum. EPSs obtained from Gleocaopsa sp. and Synecosystis reported to have the inhibitory impact on the bacterial strain of Staphylococcus aureus on dose dependent manner (Najdenski et al.,2013).

2.Anti-viral activity

EPS associated anti-viral activities are most extensively explored though the exact mechanism still not completely known. Rechter et al.,(2006)reported that EPS extracted from Arthospira platensis(Spirulin like substance) have strong inhibiting potential against Herpes simplex virus (both type 1 and 6 i.e. HSV-1 HSV-6) and HIV 1 (human immune deficiency virus type 1) where as a natural occurring sulphated polysaccharide isolated from cyanobacteria Spirulina Platensis showed inhibitory impact on HIV and Herpes simplex virus. (Hayashi et al., 1996).

Though the various studies approved their biological activities, the exact mechanism associated with these activities still remain unclear because EPS are highly sulphated and they mimics with the glycoaminoglycans (GAG) (Hayman et al., 2005).

3. Rheological properties

Cyanobacterial EPS also known to have rheological properties like in Cyanospira capsulata due to the eps production viscosity of culture medium has been reached upto 450-500 CP in 31 days batch culture, also the pseudoplastic nature of supernatants were observed in viscometric analysis (Vincenzini et al., 1990). Similar increase in viscosity of medium is observed with the Synechococcus sp. (Philips et al., 1989). The rheological analysis revealed that there is decrease in viscosity on increase in shear rate. EPSs isolated from Cyanothece (as low as conc of 0.1% w/w) (De Philippis et al., 1998) and from Anabaena sp. 0.6% w/w showed these type of properties (Moreno et al., 1998).Whereas1% w/v solution of EPS obtained from Nostoc flagelliforme showed the apparent viscosity intermediate of 0.5% and 1% w/v of xanthan gum solution (Han et al,2014), as shear rate was much faster, lead to the reduction in viscosity ,even reported two times lower than the 0.5% sol. of xanthan gum (Han et al., 2014).

Pharmaceutical and markets

Despite the various potential biological activites of EPS that could be utilized in effective drug making, the EPS based commercialized pharmaceutical drugs still non popular in the market (Laroche et al., 2022) the reason for this is not just economic but also the drastic legislation they required more clinical trials. Gaps in knowledge about complete structure and mechanism are some challenges for their commercialization.

4.Nutrition

Cyanobacteria traditionally have been used as important nutritional food supplement such as in japan the scarn (type of EPs) extracted from Aphanothece sacran is food delicacy and also good for gastrointestinal health (Fujishiro et al, 2004).Commercially two species of Arthrospira genus i.e Arthrospira maxima, Arthrospira platensisare extensively utilized in food industry, a well known sulphur containing EPS called spirulan,is obtained from them, which is also a byproduct of phycocyanin. It is considered as the rich source of protein (Lee et al., 1998). Genus Aphanothece unicellular coccoid form has been proved to be a good source of protein and could be utilized as SCP (single cell protein) for the nutrient enrichment of food suppliments (Jacob-Lopes et al., 2006; Zepka et al.,2010).

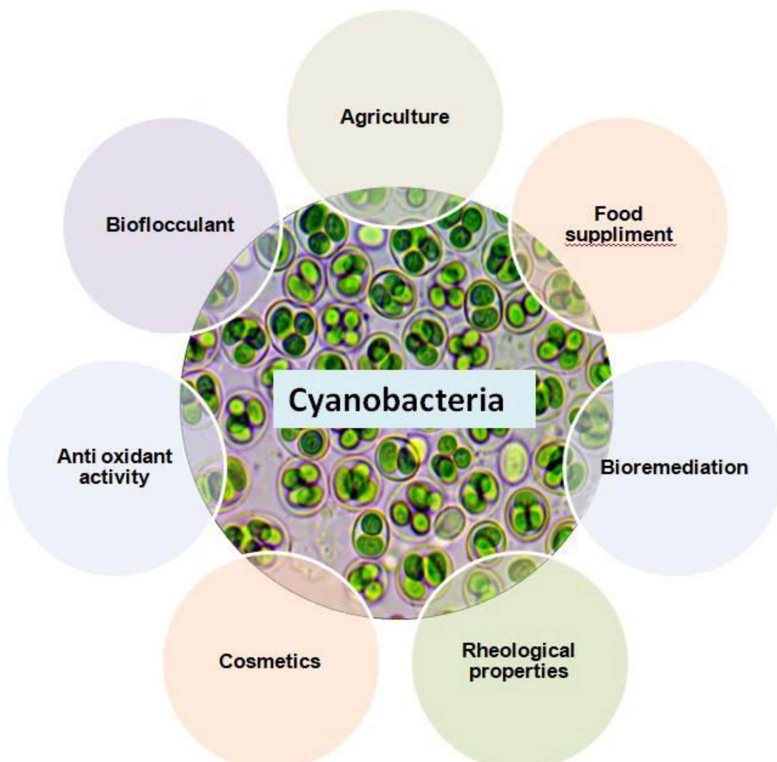
5. Bioflocculant

Bioflocculation is the phenomena mediated usually by microbes in which of adhesion or clumping of minute particles of organic matter that dispersed in aqueous environment occurs. Microbes form large flocs that settled under the influence of gravity. Though the artificial polymeric flocculants are extensively used as are of low cost but there are several heath and environmental hazards (being non biodigeradable) are also associated with them, which is need to be consider. In this regard the EPS based biofocculant of cyanobacteria are the better option since the EPS are known have a tendency to adhere and clumped. (Alam et al., 2016).

6. Hydrocollids

Hydrocolloids market is fully dominated by the seaweeds annual seaweed based hydrocolloids requirement is huge and still expanding i.e. 9600 tons for agars 26500 tons for alginate and 50000 tons for carragenans that has the market value around 1 billion sea weeds are majorly cultivated in natural condition i.e in open pond system or in sea, harvesting period is over one year and yield also vary with season and locality, making supply chain uneven, to overcome this and meet the market need ,the EPS based hydrocolloides extracted from cyanobacteria could be explored as there generation rate is much faster also require lesser space for harvesting.

Figure-2: Applications of Exopolysaccharides



Restoration of Degraded Dry Lands:

When cyanobacteria is inoculated on soil surface, it produces EPS which causes certain changes in soil properties beneficial for the soil quality.EPS produced by cyanobacteria are sticky that binds with the sand grains (Mugnai et al., 2018) due to which a cohesive and stable layer is formed which would help in minimizing the soil erosion (Fallahi et al., 2020) that is well known to accelerate the process of soil degradation.

Though the seaweed polysaccharides already been extensively utilized as plant defense inducers, yet the microalgae polysaccharides application in agriculture need to be explored. Faridet et al., (2019) studied the four strain of microalgae and observed that these microalgal polysaccharides act as a biostimulators of multiple biochemical and metabolic reactions linked to plant defense mechanism including lipid remodeling and stimulation of those enzymes that are key defense enzymes such as Lipoxygenase (Fujita etal.,2006),β-1,3-

glucanase and phenylalanine ammonia lyase. Their study indicates that microalgal polysaccharides could be potential renewable bio-resource in the development and innovation of products for enhanching plant tolerance towards the biotic and abiotic stress in the framework of sustainable agriculture management.

In Heavy Metal Absorption

Cadmium, a toxic heavy metal majorly used in industrial process is a prominent water pollutant. It is reported that fixed bed absorbent system produced from Aphanothece sp. is capable of removing cadmium Cd efficiently from aqueous solution (Satya et al., 2021). Singh et al., (1999), studied the impact of Hg, Ni, Cu on thiol and exopolysaccharide synthesis in Nostoc spongiaeforme. Their observation indicates towards the positive correlation between the thiol production and certain concentrations of Hg, Cu, Ni metal ions, though the effect was within a threshold limit. Under metal stress cyanobacteria adopt a strategy to target the metal complex at the cell interior (polypeptide precurcers) known to bind metal ions by enhancing thiol synthesis.

The study on tomato crop revealed that heavy metal stress (Pb and Cd) reduces the plant growth and generation of photosynthetic pigments due to the ROS (reactive oxygen species) production and nutrient uptake disruption. It was further observed, by the Fal et al., (2023) that the Aphanothece crude extract (ACE) application on the crop showed the corrective effects on yield. The plant growth increased and production of photosynthetic pigments also enhanced. ACE application induces the heavy metal accumulation more in roots and inhibit their upward translocation to shoot, thus their study revealed that microalgae (Aphanothece sp.) could be used as biostimulant of plant tolerance towards the heavy metal and in the better phytostabilization strategy (Fal et al.,2023).

El-Enany etal., (2000), studied the impact of sewage on the physiological activities of two Nostoc strains. They compared the Metal tolerance of Nostoc rivularis with N. linckiaand, their growth rate showed positive impact in moderate and low levels (25%for N. rivularis and 50% for N. linckia),time required to reach exponential growth also reduced. They observed that the N. rivularisis more sensitive towards the heavy metal than the N. lincika and had accumulated less metal binding proteins. N. linckia found to be moretolerant towards the heavy metals (Zn and Cd),it accumulate the ions of metal by adsorption on the cell surface and able to sequestrate with the help of metal binding protein, thus could be used in the restoration of water bodies contaminated with heavy metals Zn and Cd.

Micheletti et al.,(2008), studied the nine different strains of EPS forming cyanobacteria for knowing their efficiency to remove Cr, Cu and Ni (in both single and multiple metal solution) and they concluded that the strain of Cyanothece16 Som 2 had greater sorption capacity among the all, Nostoc PCC7936 strain was highly specific and exclusively selective for cu metal ions thus could be utilized for the recovery of Cu metal from the solution containing multiple metal ions.

Although heavy metal removal by cyanobacteria is quite effective method but there are some limitations responsible for its limited use, as methods involving cynobacterial applications are much slower than the traditional chemical Processes (Palaniswamy et al., 2017). Moreover, introduction of Cyanobacteria could posses a severe threat to native aquatic ecosystem as some of them reported to be toxic such as Anabaena circinalis, Cylindrospermopsis raciborskii, Microcystis aeruginosa, Planktothrix sp. and Nodularia spumigena CCY 9414 (Falconer et al, 2005; Doshi et al., 2009).

Exopolysaccharide in Cosmetics:

In today world the growing concern over health, aging and appearance lead to the preference of those cosmetics that are based on the natural sources, this started a quest for the bioproducts with potential cosmeceutical properties and in this regard the cyanobacteria along with the plants, eukaryotic microalgae have been extensively explored (Morone et al.,2019).Though the sunscreen that contain synthetic UV filters are effective against the UV radiations but they can cause detrimental effects to human and environment. many research reports indicate their potential side effects such as endocrine disrupter (Ozaez et al., 2013) and contact dermatitis in children (Audran et al, 2010),also their residues have been reported in STP surface waters, river sediments (Zhang, et al,2015)and causing toxicity to several organisms (Wang et al.,2016). For the eco-friendly photoprotective compounds the cyanobacteria could be explored. Gao, X. (2017). Scytonemin plays a potential role in stabilizing the exopolysaccharidic matrix in terrestrial cyanobacteria.

As cyanobacteria are adapted to the strong solar radiation due to the presence of biomolecules like mycosporin like amino acids (MAAs) and Scytonemin (Scy)[Gao, 2017; Singh et al.,2010].MAAs are known to be involved in photo protective mechanism of cyanobacteria. Several MAAs have been reported from the cyanobacterial strains such as Porphyra-334 and Shinorine werefound in 3 species of Nodularia genus (i.e Nodularia spumigena, N. baltica, N. harveyana)[Sinha et al.,2003]and some modified MAAs (glycosylated) have been isolated from astrain of Nostoc sp. (Matsui et al., 2011). Other commonly occurring Maas that have been reported from different cyanobacteria strains, such as asterina-330 euhalothece-362, mycosporin-glycine, mycosporine –tau, palythene and palythinol (Rastogi et al ,2010).

Besides the MAAs, SCY are the part of exopolysaccharide sheath in cyanobacteria, SCY is often produced by cyanobacteria on exposure to ultraviolet radiations (UV), it is interesting to found that it reduces the UV penetration to the cell by 90%. It shows highest absorption at 370nm, and when purified it had an absorption of386nm (Jones et al., 2011; Rastogi et al.,2010). As MAAs and SCY are effective towards the photoprotection, these biopigments could be better alternatives in sunscreens.

Sacran which extracted from the extracellular matrix of cyanobacterial strain Aphanothecesacrum, reported to have to theresidual sugar moites like mannose, muramic acid and uronic acid (Okajimaet al., 2009). Moisture retention capacity of Sacran and hyaluronic acid has been compared by Zhao et al.,2013 and it was observed that it has a higher viscocity, good water absorption potential and ability to absorb metal ions Ca^{+2}, Mg^{+2}, salines. Thus sacran could be better alternative for moisturizing agent in cosmetics as hyaluronic acid is costly and has a limited production (Morone et al, 2019).Potential of cyanobacterial biocompounds as skin moisturizer, UV protector and protection against the ROS indicating their application in anti-aging products also (Gao et al, 2021) In skin the fibroblast are responsible for providing firmness and elasticity to dermis (Frantz et al.,2010); The Arthrospira platensis extract were reported to enhance cell viability, effectively reduces the DNA destruction as it inhibit the formation of thymine dimers and matrix metalloproteinase (MMP) in the dermal fibroblasts (skin cells)that are exposed to ultra violet radiations (UV-B)(Lee et al, 2017).

The high water holding tendency of Cyanobacterial EPS also their antibacterial and anti-inflammatory properties made them suitable for pharmaceutical application. Recent studies shows that the EPSs could be used in wound healing bandages (Laroche et al.,2022), the wound dressing made from the EPSs from Nostoc sp. have been tested successfully in vitro, confirming their ability to induce fibroblast migration and proliferation that is the principle factor in regeneration and repair process of dermis (Alvarez et al.,2021). Moreover, Bhatnagar et al., (2014), studied and tested the four EPSs obtained from cyanobacterial strains i.e. Tolypothrix tenuis and three Anabaena species for their hemostatic activity, EPSs from Anabaena sp. found to be reducing the clotting time significantly thus suggesting these wound healing hydrogels could also be utilized in hemostatic dressing apart from skin injuries recovery.

Genetic modification

Desirable characteristics of the selected species can also be enhanced via targeted genetic engineering or indirect mutagenesis methods. Eukaryotic organisms having complicated genetic composition, and the number of model species remains low. On contrary the genetic modification (GM) is considerably more robust in cyanobacteria, which have the benefit of being prokaryotic cells with greater transformation tendencies. Globally the production of many high value compounds gained popularity via genetic engineering that improves the mass production of cyanobacterial strains (Teng et al.,2020). However, the production of GMOs (Genetically modified organisms) continues to be a contentious and challenging issue in many nations, including the EU, thus commercial cultivation of GMOs remains uncommon.

EPS Extraction Methods:

Selecting an suitable extraction process is crucial for determining the structural characteristics of EPS. According to Comte et al. (2006), the extraction process affects both EPS yield and cell rupture, as well as its chemical makeup.EPS could be extracted using different methods mentioned in various research literature (Underwood et al.,1995; de Winder et al., 1999; Dechoet al., 2005).

Strieth et al.,(2020) noted that factors such as culture media, mass, pH and gas transference rate, light and inoculums conditions impacts the Cyano-EPS Optimization. Also the location of EPS must be considered as it would strongly affect the downstream process. Thus it is necessary to comprehend the kinetics of biomass and EPS formation for the specific growing conditions and choose the most convenient strategy.

Extraction of EPS containing sheath is can be carried out by homogenizing cyanobacterial cell via differential sucrose gradient (Bertocchi et al., 1990). Solubilization of cellular polysaccharides achieved by treating the cell pellets with warm water (Bertocchietal.,1990) then washing with deionized water (Nakagawa et al.,1987;Plude et al.,1991); then at 100^0C, cell pellets could be resuspended in buffur solution (Filali Mouhim et al.,1993), orbyasodium chloride solution of 1.5%from extraction of cell pellet at 60^0C (Vincenzini et al., 1990; De Philippis et al., 1993). EPSs precipitation is usually carried by alcohol usually achieved by alcohol treatment from cell free supernatants (Li et al., 2001). Detailed methods associated with the extraction of cyanobacterial EPS and their characterization method are given in Figs 3 and 4.

Conclusion:

As compared to the other microbial polysaccharides, there are fewer investigations on exopolysaccharide obtained from cyanobacteria. There are many gaps in understanding their structure physiochemical properties, production and extraction process. These aspects require further consideration. EPS characterization includes identifying the monomer units (monosaccharide types and other associated molecules), their sequence, Branching patterns, anomeric configuration and also isomeric location of each glycosidic bond which makes their analysis challenging.

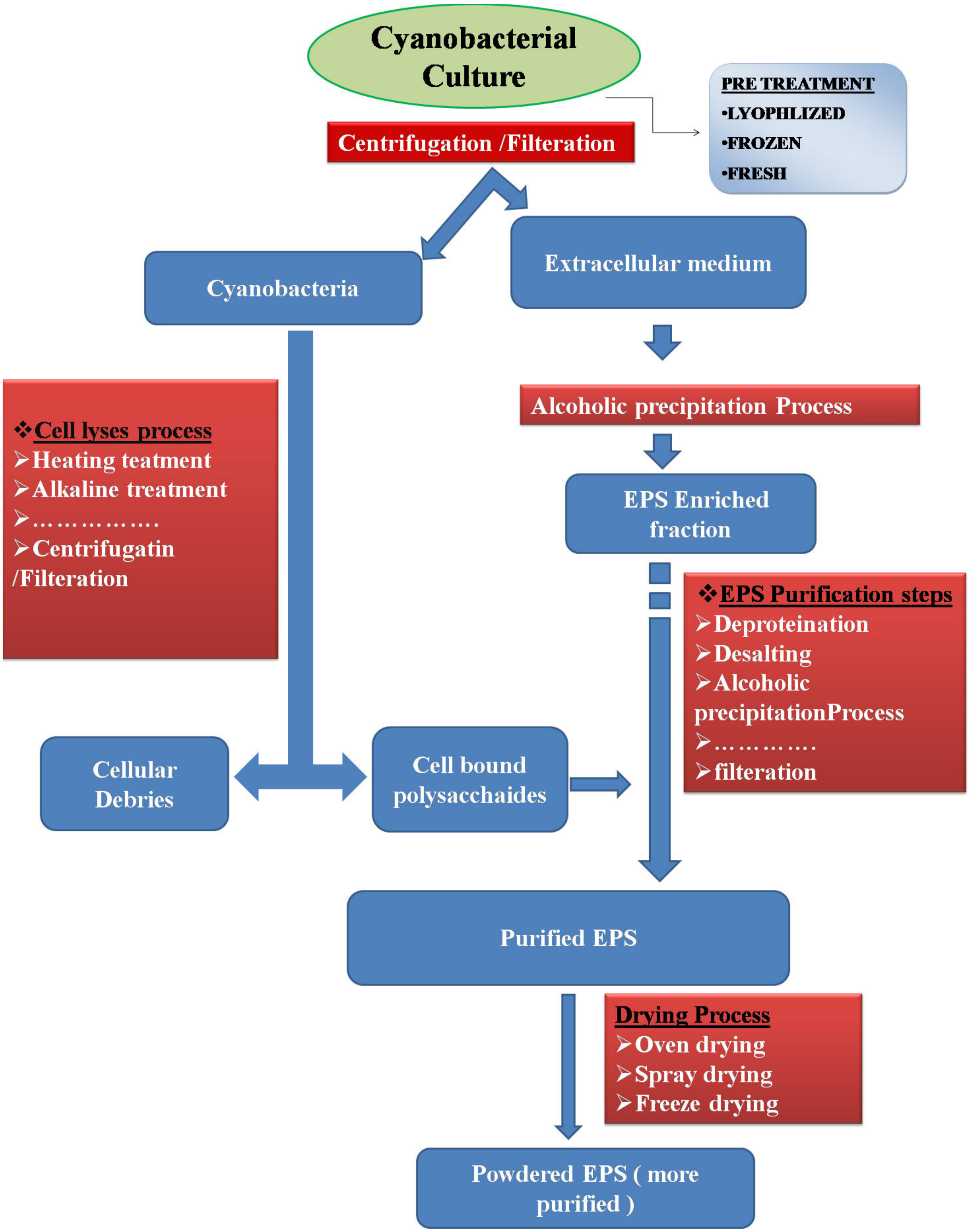


Figure-3. Extraction process of exopolysaccharides

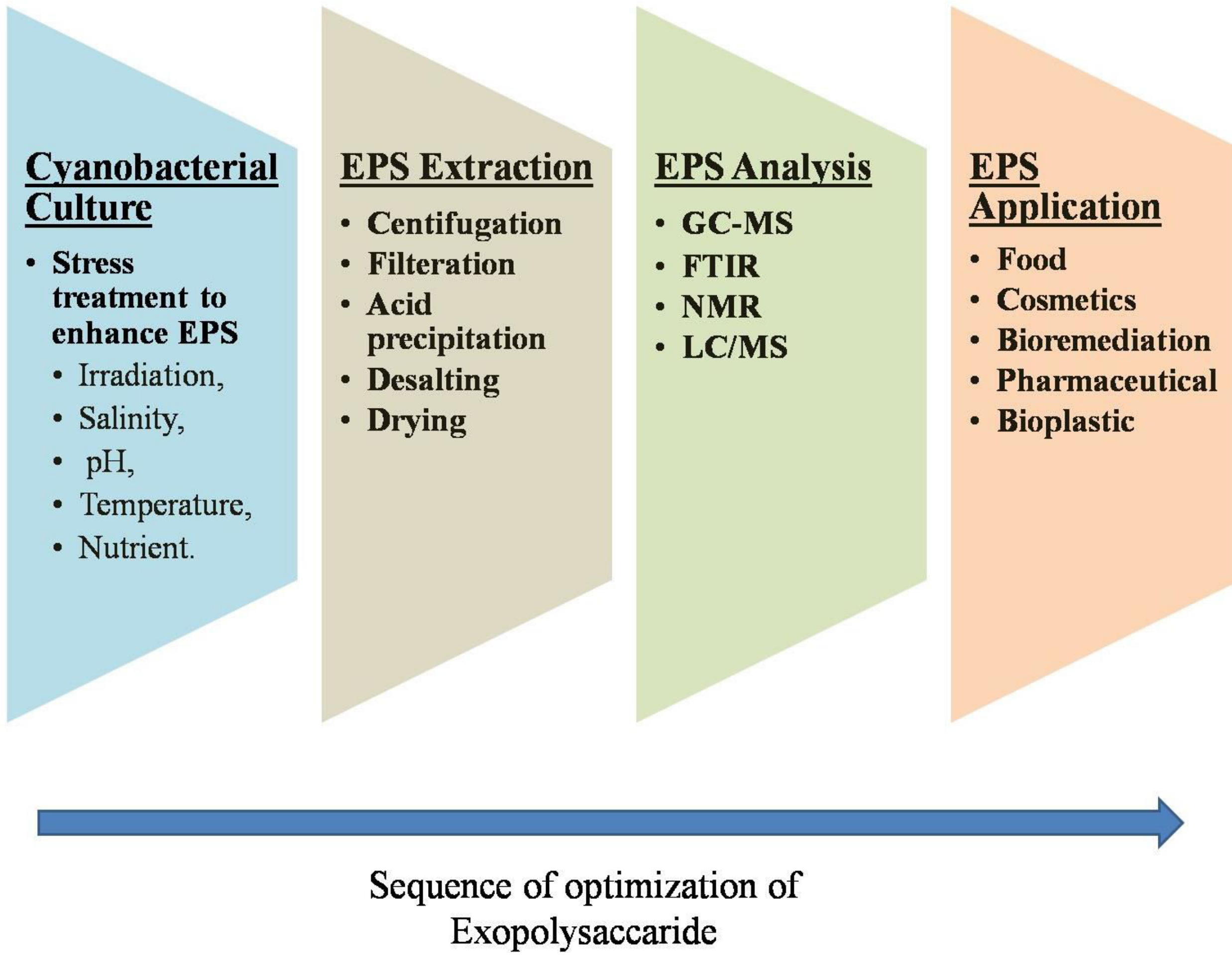


Figure- 4. Characterisation of Cyanobacterial Exopolysaccharides.

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