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The Realm of Biopolymers and Their Usage: An Overview

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Abstract
Biopolymers are emerging as an advanced business sector progressively and gained the attention of researchers and industrialists. Polymeric materials are useful due to their flexibility, reusability and toughness nature. These biopolymers can be the amalgamated with various kinds of natural and synthetic materials to synthesize polymeric composites. Such composite materials have comparable properties to oil-based polymers. Biopolymers also play an essential role in the drug and pharmaceutical industry. These can be utilized for industrial purposes, for instance, to regenerate damage, medication administration in addition to regenerative medicine to achieve, low immunogenicity, high pharmacological activity. Several biopolymers are described in this article. There are various mechanisms to produce biopolymers. There are diverse forms of biopolymers that originated from microbes, animals and plants. Biopolymers play a significant role in the chemical and pharmaceutical industries. These are extensively used in medical equipment, cosmetics, confectionery, wastewater treatments, food additives, textiles and in bio-sensing applications. Numerous possible applications, along with the production form of biopolymers, are reviewed in this article.

Keywords: Biopolymers, Circular economy, Keratin, Collagen, Cellulose

1 Introduction
Biopolymers are produced from living creatures as the polymeric structural- substances that exhibited properties such as strength, steadiness and flexibility. These include parts of crops or plants or obtained from various kinds of animals and microorganisms (1, 2). These immediately overlap to acquire different shapes and profoundly delicate structures with a high level of strong security. The significant plant biopolymers origin are cellulose, pectin, hemicellulose and lignin, which have immense industrial importance (3, 4). The marine fauna and flora also impart a significant fraction of biopolymeric ingredients. Biopolymers have been classified on the basis of biological nature such as proteins, carbohydrates, lipid wax, polyphenols nucleic acids and polyhydroxyalkanoates (PHA) (2). These are generated from renewable sources i.e. natural resources and are readily degradable by enzymatic action because of the presence of peptide and glycosidic bonds. The byproducts of biodegradation of biopolymers are H_2O, SO_2 CO_2, and other organic materials. Biopolymers are thus naturally converted into reusable material by biological processes (5). Alginate, are abundantly present in brown algae (pheophyta) of the genera "*Ascophyllum, Cystoseira, Macrocystis, Laminaria, Alario, Eisenia, Nercocystis, and Sargassum.* Another important biopolymer is Carrageenan, obtained by extraction from red seaweeds *(Rhodophyta)*. The significant genera used for the removal of carrageenan are *Chondrus crispus, Eucheuma Gigartina, and Hypnea* (6). The immobilization system of yeast cells (*Saccharomyces* sp.) for liquor utilising κ-carrageenan beads is one of the popular example in liquor industry. Ethanol production through glucose by utilizing cells of *Zymomonas mobilis* immobilized in κ-carrageenan was studied in a fluidized bed fermenter. The whole cells of *Streptomyces aureofaciens* immobilized in κ-carrageenan were also used for the production of tetracycline and chlorotetracycline. Biopolymers have also immense applications in bioremediation and pesticide degradation. The degradation of Pentachlorophenol in contaminated soil was performed using *Pseudomonas sp.* UG30 cells immobilized onto κ-carrageenan (7). The biopolymers of animal origin such as chitin, keratin and collagen also have various applications in the food and pharmaceutical industry. In this review, we highlighted the sources, extraction, production and applications of all these biopolymers.

2 Role of biopolymers and importance in nature
Living creatures produce a wide range of polymers as a significant part of their morphological, cellular and dry matter. These biopolymers play a vital role in the life cycle of organisms to support their essential metabolic and cellular activities. A schematic diagram has been presented in Fig. 1. Biopolymers are produced in the cytoplasm, organelles, cytoplasmic membrane, cell wall components, and the surface of cells even

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extracellularly by enzymatic processes. Synthesis of a biopolymer may be commenced in one part of a cell and then maybe continued in another role as it happens. Many biopolymers can be extracted from plants and algae, which build up in organic habitats. For example, nutrient agar and alginin are extracted from genus *Gelidium* red algae or from numerous brown algae, also known as seaweeds (8). Hyaluronic acid is an exception, which is taken out from the umbilical cords of newborn children. Some biopolymers are *in vitro* synthesized with the help of purified enzymes in cell-free systems. For example, in the polymerase chain reaction (PCR) monodisperse defined DNA molecules are developed from heat resistant DNA polymerases. One more example is dextran, produced from isolated dextran sucrose (8). Biopolymers, e.g. starch, dextran can be provided through fermentation processes in industries. The biological production of biopolymers may occur intracellularly or extracellularly, which creates trouble in the downstream processing of the biopolymers in a purified state (8).

3 Analysis of various biopolymers with their applications

3.1 Biopolymers of animal origin and their applications

3.1.1 Keratin

Keratin is an organic material, which speaks to a gathering of cysteine-rich filament proteins. It is a member of a fibrous protein family (9, 10). For the epidermal appendages such as talons, neb, nails, wool, hair, horns and plume, it acts as a safeguard sheet (11, 12). On the basis of auxiliary order, the protein is categorized as α and β keratin. In water keratin is insoluble; and can be partially assimilated through proteolysis, for example, pepsin, papain or trypsin.

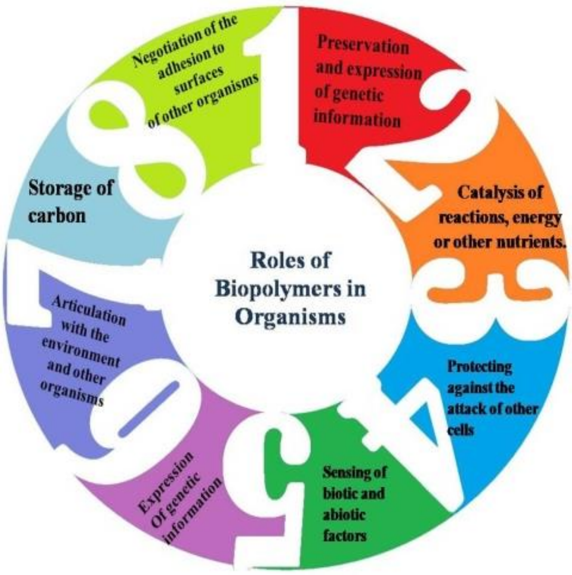

Fig. 1: Biological role of biopolymers in living organisms

Furthermore, their complex structures like nanofiber lattice structure and the polypeptide chains make a barrier to save from warm pressure morbific intrusions (especially by epidermis), machine-like harm, and so on (13, 14). Epithelial cells are the most extravagant compartment for keratinous auxiliary protein. Hairs assume a significant job of security against residue and pathogens (hairs in nostril). Bovid animals like cow, waterbuck, sheep, buffalo, and gazelle pass on keratinous material as horn. Horns act as a weapon, sometime(s) as a shield to protect from predator and fight with various animals for their defence (12, 14).

The turtles have a durable sheath in which carapace has elevated proportion of α/β-keratin. Nails are a significant source of α-keratin. In primates, nails of fingers highlight at the time of battling, scraping and to open some objects (12, 14). The enzymes are generally utilized for the transformation of keratinous squander into feed, manures and fertilizers. The microbial catalyst (protease, e.g. keratinases) acts on keratinous protein substrates and discharges free amino (– NH_2) group molecules (12, 15). Keratin is present in cattle hides, goatskins, sheepskins, and buffalo hides. The major sources of keratin sources are appendages, skin, fingernails, hairs of the head, cloven hoof, scute, a layer of skin feathers, and wool (11, 16). Keratin is composed of amino acid chains with numerous functional groups, both on the spine and side chains, which can tie metal particles and colours (17, 18). It is among the most plenteous and often immaculate non-food proteins. Consistently, over 5 million tons of keratin squander is created on the planet (19). A few investigations were demonstrated that the keratin nanoparticles were utilized for the finding of Crystal Violet from watery medium (20). Keratin from quills used to make strands, films, hydrogels, miniaturized scale and nanoparticles with the end goal of food, clinical, cosmetology, material, composite, farming and different businesses (17, 18, 21).

The nearness of keratin in the skin layer and hair fingernail skin helps in holding dampness in the skin by interfacing with beautifying agents. Plumes can be utilized to make thermoplastic shield for bundling of food and different applications (12, 16, 22). Keratinolytic enzymes are produced by bacteria and fungi that help to degrade the waste biomass. Bacilli create a lot of keratinolytic proteins and actinomycetes additionally add to keratin debasement. Microorganisms are used for quill debasement as it is profitable and naturally safe type of the persistently amassed squander the executives (14). The commercial use of keratin from waste biomass not only protects the ecosystem but also boost up the cosmetics and pharmaceutical industry (11, 23). In a previous study, polyvinyl liquor filaments that contain keratin were utilized as permeable for harmful material such as substantial alloy particles and formalin it indicates the porous nature of keratin particles (12, 22). Also, for the delivery of drugs keratin particles were mostly used because of its durability, low reactivity, auxiliary, and excellent mechanical stability. Being a standard polymer, keratins have the edge as it is rich in amide, carboxyl, hydroxyl, just as sulfhydryl, and these functional groups increase their interaction with naturally unique atoms. A nano-based PEG-instigated keratin composite was used for drug delivery (12). Food processing industry, particularly slaughterhouse, wool industry produces millions of tones of keratin containing biomass. The monomeric units of ordinary keratin can penetrate the skin and hair fingernail skin and protect the skin without any responses (1). Keratin is also a fair source of nitrogen used as an ingredient of fertilizers (24, 25). Keratin based crest having high surface area were used as anode material in electrochemistry (26). Keratin squanders can be used in cowhide tanning. Keratin hydrolysate is used in filling cum holding in cowhide (27). The various biopolymers of animal origin and their applications are listed in Table 1.

3.1.2 Collagen

Collagen is the vital auxiliary biopolymer synthesized by fibroblasts and 20–30% of total body proteins of mammals. They are rod-shaped, and collagen has 300 kDa molecular weight (28). The body can efficiently absorb it and has extremely low immunogenicity.

Table 1: Biopolymers of animal's origin and their applications

	Name of polymer	Source of origin	Physical appearance	Uses/applications	References
1	Hyaluronic acid	The umbilical cord of newly born child, from rooster combs, fermentation broths of streptococcus and other bacteria.	Transparent, viscous fluid or white powder.	Gel preparation for drug delivery, wound healing, cosmetic products, viscosity agent, filler in medicine, antibacterial.	(2, 8)
2	Chitosan	Shellfish and crustacean waste materials	Pale, white and flaky and its moisture content was 10.9%.	Cosmetic industry, medicine, agriculture, waste treatment, wound-healing treatment, paper manufacturing, food packaging, seed coating, plant growth regulator, recover protein wastes, manufacturing, personal hygiene products, anti-bacterial, anti-acid, drug carrier for controlled release, a flocculating agent, purify drinking water, bioremediation of toxic phenolic compounds, promote osteogenesis, fat absorbent action.	(2, 8)
3	Gelatin	Cattle hides, bones, fish, pig skins, agricultural or non-agricultural	Water-soluble translucent, flavourless food ingredient, gummy when moist and brittle when dry	Stabilizer, thickener, texturizer, emulsifier, foaming, food wetting agent, pharmaceutical and medical usage.	(29)
4	Keratin	Feathers, hair, nails, wool, horn and hooves, stratum corneum And scales.	Insoluble in most organic solvents.	Absorbents, leather industries, drug delivery system, surgery, food industry, cosmetics, biomedical products, fertilizers, electrode material.	(9-12, 14, 15)
5.	Collagen	Invertebrates in the body walls and cuticles.	Hard, fibrous, insoluble, protein, and molecules form long, thin fibrils.	Sutures, dental composites, sausage casings, skin regeneration templates, cosmetics, biodegradable matrices, solid-support microcarrier in the production of enzymes.	(30)

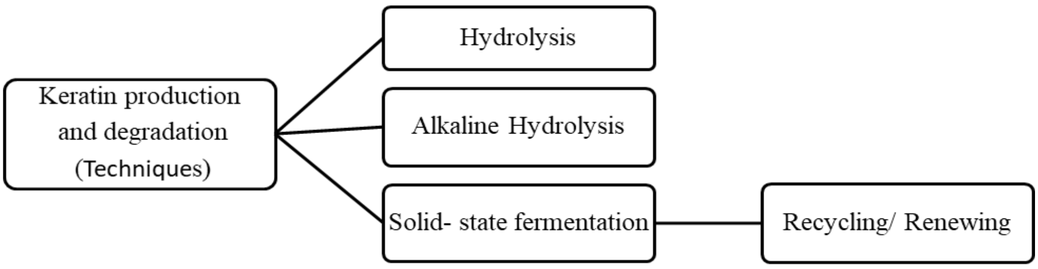

Figure 2: Schematic diagram representing the methods of production of keratin

Collagen film and/ or matrix have been utilized as nucleic acid and protein transporters to assist bone repairs (31). Collagen sponges have been used in the treatment of severe burns and as a dressing for acute injuries. Collagen hydrogel was also utilized as genetic material delivery carriers. The collagen nanoparticles and/or nanospheres are thermally stable, thus, promptly achieve their sterilization. Nanoparticles have been utilized as an anti-cancerous agent such as camptothecin and hydrocortisone bearer for parenteral administration and other therapeutic compounds (32).

3.1.3 Gelatin

Gelatin is a proteinaceous substance, which is water-soluble prepared by the incomplete hydrolysis of collagen obtained from the bones of animals, skin, and white fibrous tissue. Gelatins are quite different hydrocolloids, and the majority of them are polysaccharides. It is an edible proteinaceous compound containing all the basic amino acids except tryptophan. The standard commercial sources for gelatin are cow bones, hides, pig skins, and fish. Gelatin has been widely used as emulsifying, foaming, and wetting agent in food, medical and pharmaceutical, industries because of its surface- dynamic properties (33). Gelatin has been utilized in the nourishment and covering wieners for meat items.

3.1.4 Hyaluronic Acid

Hyaluronic acid is a well known mucoadhesive polysaccharide. It is very much dispersed in an extracellular grid and the joint fluids of vertebrates. Hyaluronic acid polymers are presently utilized in the planning of gels for medications to eye and establishment into different depressions.

Along with varying polymers like alginic acid, hydroxypropyl methylcellulose, poloxamers hyaluronic acid can be utilized to fulfil the ideal feature in tranquilize conveyance frameworks (34). It is also utilized as a thickening agent in aspiratory pathology for accomplishing alveolar patency and as filler in exhilarating medication for crinkles and cutaneous lines (35).

Table 2: Biopolymers of plant's origin and their applications

Name of polymer	Source of origin	Physical appearance	Uses/applications	References
Cellulose	Plant tissue (trees,cotton etc), bacteria (*Acetobacter xylinum*).	Water indissoluble, chemical-free solvents odourless, hydrophilic, environment-friendly.	Controlled Drug Delivery Devices, Wound Dressings, Scaffolds for Regenerative Medicine, cellophane films, thickener, wrappers, adhesives, agricultural chemicals, coatings, ligature, preserver, dispersing agent, flow controller, tile sealant, board fixative, indelible inks, beauty products.	(1, 2, 36)
Pectin	Plant cell walls, citrus peels, apple pomace.	Coarse or fine-powder, yellowish-white, odourless, mucilaginous taste, altogether soluble in 20 parts of water.	Reduce blood cholesterol, treat gastrointestinal disorders, remove metals such as lead, mercury from intestine and lungs, control haemorrhage, tablet formulations, antimicrobial action, improves coagulation, treatment of overeating, anti-inflammatory.	(2, 37, 38)
Carrageenan	Cell wall matrix of red seaweeds.	Large, pliant molecules and make helical structures, at room temperature, gets solidify.	Anticoagulant and antithrombotic activity, Antiviral activity, textural functionality particularly in dairy products.	(39)
Xylan	Hardwood (eg- *Eucalyptus globules* etc), almond shell, rice husk, corn cobs.	Yellow gummy highly complex pentosan.	Low-caloric sweetner, preventative agent, paper making, textile printing, drug delivery system.	(40, 41)
Guar Gum	*Cyamopsis tetragonolobus or Cyamopsis psoraloides.*	White to an off-white colour, unscented, greyish white granulate 90% of which dissolves in water.	Disintegrating agent, binding agent, film-forming agent, viscosity-enhancing, thickening or gelling agent, stabilizer, emulsifier, bioadhesive agent, bulk-forming laxative, non-toxic nature.	(42)
Alginate	Brown algae of the genera '*Nacrocystis,Laminaria , Ascophyllum, Alario, Ecklonia, Eisenia, nercocystis, sargassum, cystoseria,fucus*	White to yellow, fibrous powder.	Fruit texturization, diffusion-set gels, protein expulsion, increased shelf life of potatoes, restraining banana enzymes, crumble fish patties, flesh products, water-holding, ice cream stabilizers, dispersive ability.	(43)
Gum Arabic	Stems and branches of *Acacia Seyal and Acacia Senegal* tree.	Dried, gummy. white to yellowish white, practically with tasteless, and odourless.	Stabilizer, thickening agent, emulsifier, fabric,ceramics,print photolithograph, beauty products,medicine manufacturing industries, treatment of internal as well as external inflammation , antioxidant, nephroprotectant .	(44)

Viscosupplementation with Hyaluronic acid items improves the body's function in an osteoarthritic joint by enhancing the stun retention and grease properties of the synovial liquid. Furthermore, it reestablishes the defensive viscoelasticity of synovial hyaluronan, diminishes torment, and improves portability. Esterified hyaluronic acid is utilized to avert bacterial grip to dental inserts, intraocular focal points, and catheters (45).

3.2 Biopolymers of plant's origin and their applications

The various biopolymers of the plant's origin and their applications are listed in Table 2 and discussed below.

3.2.1 Chitosan

Chitosan is a natural carbohydrate obtained from chitin. Second most abundant biopolymer on this planet is chitin and can be extracted from mushrooms, the exoskeleton of shellfish and bugs, nematodes and in the cell mass of yeast and parasites. Chitosan has numerous properties like high bioactivity; biocompatibility; penetrability; biodegradability; antimicrobial movement; explicit polyelectrolyte action; chelation ability capacity to form gel, film, and absorptive limit. Thus it makes the chitosan as an important tool in various fields, for example, drug carrier for controlled release, bone tissue building, inhibits the bacterial plaque formation anti-bacterial and anti-acid; promotes Osteogenesis, fat absorbent action decalcification of dental enamel promotes the healing of ulcers and injuries (46). A quick injury recuperating, hydrogel sheet was made with a blended powder of alginate, chitin/chitosan and fucoidan for wound dressing (47). Besides these, it has been utilized for ligament tissue building, wound mending and orthopaedic applications—degradable polymeric lesser down the prerequisite for a second, careful activity. Chitosan has been appeared to have antimicrobial activity in various microorganisms, including growths, green growth and organisms. For instance, it showed antimicrobial action against gram-positive bacteria and assorted types of yeast. The chitosan gel was also reported as a preventive and medicinal candidate for dental caries (48).

3.2.2 Cellulose

It is a polymer of glucose, exist as a major constituent of plants in abundance (49). Cellulose is a polysaccharide having a direct chain of two or three hundred to in excess of ten thousand β (1→4) associated D-glucose units $(C_6H_{10}O_5)n$. Because of the astounding biocompatibility of cellulose and its extraordinary mechanical properties, the cellulose is used as biomaterials for the tissue designing frameworks. Bacterial cellulose (BC) has been investigated for wound recuperating as a result of its virtue and high water maintenance limit (49). Cellulose is broadly utilized for the generation of wrappers and coatings. Cellophane films, appropriate for nourishment bundling, are made up of cellulose.

Table 3: Biopolymers of microbial origin and their applications

	Name of polymer	Source of origin	Physical appearance	Uses/applications	References
1	PHA Polyhydroxyacetonoate	*Cupriavidus necator(Ralstonia eutropha* or *Alcaligenes eutrophus*).	Pliant,adjustable,amorphous.	Shaving instrument, household articles, nappies, sanitary towels, beauty products, shampoo containers, bone plates, surgical stitch, blood vessel replacements.	(50)
2	Pullulan	*Aureobasidium* pullulans.	White powder dissoluble in water, uncoloured and gluey adherent solution, indissoluble in solvents such as ethanol, methanol and acetone.	Inhibits fungal growth, low-viscosity filler, stabilizes the quality and texture, binder and stabilizer, protective glaze, stabilize fatty emulsions, denture adhesive, pharmaceutical coatings.	(8, 51)
3	Levan	*Rothis dentocariosa, Streptococcus salivarius, and Odontomyces viscosus, (Bacillus subtilis, Bacillus megaterium, Bacillus cereus,* and *Bacillus pumilus.)*	Natural adhesive and surfactant, non-viscous and water and oil soluble	Emulsifying agent helps in preparation, preserver, gelatinize, surface-quality agent, encapsulate, carrier for savour and odour, photographic emulsion, molecular sieves for gel filtration, blood volume extender.	(52)
4	Dextran	*Dextran sucrase, Leuconostoc mesenteroides, Saccharomyces cerevisiae, Lactobacillus plantarum*, or *Lactobacillus sanfrancisco*.	Dissoluble in water, dimethyl sulfoxide, formamide, ethylene glycol, glycerol and indissoluble in monohydric alcohols, e.g., methanol, ethanol, isopropanol, and ketones, e.g., acetone and 2-propanone	Solidifying agent, thickening agent, improves surface quality,emulsifier in edible products, soothing, palatable, loaf mass, smoothness, storage life, cryoprotectant, viscosifier, creamy, lower synaeresis, antioxidant for food, water holding capacity, moisture content raised in non-fat mass, functional foods.	(53)
5	PHB (polyhydroxybutyrates)	Microorganisms (such as the *Cupriavidus necator*, *Methylobacterium rhodesianum* or Bacillus *megaterium*).	Biodegradable thermoplastic polyester. Highly crystalline (>50%), brittle and hard.	Osteosynthetic materials, biodegradable carrier, biocompatible, maintain cell development, guide and arrange the cells, growth of tissue, scaffolds, food packaging.	(54)
6	Bacterial Cellulose	*Achromobacter, Alcaligenes, Aerobacter, Agrobacterium, Azotobacter, Gluconacetobacter, Pseudomonas, Rhizobium, Sarcina, Dickeya, and Rhodobacter* belong to the Komagataeibacter genus	Intact membranes (fibres form or pellets form,), disassembled BC, and BC nanocrystals (BCNC).	Packaging for foodstuffs, transparent covering, cell divider,permeable, medicine manufacturing industries, water investigation, beauty products, biocompatible, ethyl alcohol manufacturing, conduct electricity, magnetic stuff,manmade blood vessels, scaffolds for tissue engineering.	(55, 56)
7	Curdlan	*Agrobacterium* genus, Gram-negative bacteria	White granulate, fragrance-free, non-poisonous gel, steady at 3 to 9 pH scale.	Stabilizer, bio thickener, immobilizing materials, Texturizer, binding agent, as immunostimulator.	
8	Xanthan gum	Plant pathogen such as *Xanthomonas campestris* NRRL B-1459.	Motile, having a single polar flagellum, cream coloured powder soluble in both cold and hot water.	Emulsifier and thickening agent texture, viscosity, flavour release, appearance and water-control.	(57, 58)

These materials are viably used for the packaging of meat, frozen yogurt, parlor things, and cheddar. Also, cellulose-based enzyme immobilization is used to improve the biocatalytic characteristics of enzymes. It has been noticed that there are many other carriers such as celite, silica, for enzymes immobilization (59-61). Cellulose-based natural fibres and nitrocellulose membranes have also been used for the immobilization of lipase in the previous studies which significantly improved the reusability and catalytic properties of the enzyme (62-66). Also, the cellulosic nanogel prepared from cellulose was used for the immobilization of lipase containing cellulose-binding domain at its N-terminal end (67). Cellulose-based nanocomposites were also used for the immobilization of enzymes which enhanced its catalytic performance (68). Beside enzyme, immobilization cellulose was also reported to synthesize other products of industrial importance such as bioethanol, biobutanol, biochar etc. Biomass-based biofuel and biochar has immense applications in wastewater treatment in the bioenergy sector (69, 70). Microbial enzymes in free and immobilized form, such as cellulase, xylanase and beta-glucosidase have been reported to hydrolyze the cellulose into biofuels from various sources (71-75).

3.2.3 Xylan

Xylan is a hemicellulose and used as a polysaccharide after cellulose. In hardwood xylans plants and oats making up to 30% of the cell divider material and lignocellulosic materials. Xylan has been utilized as a crude fitting matter to make colonic drug conveyance frameworks. The viscosity of fibre and water-extractable ability helps in bringing down the blood cholesterol, postprandial glucose, insulin reaction and professed to ease alcoholic liver issue respectively (76). Hemi-celluloses having xylan extracted using waste from plants, such as wheat straws, bamboo leaves, and corn stalks are accounted to hinder the development pace of sarcoma 180 and different tumours. T-lymphocytes and immunocytes are enacted through carboxymethylated xylan and hemicelluloses. Pentosan polysulfate (PPS) is known as a foe of coagulant, and in the gel structure is used in the treatment of implantation thrombophlebitis (77).

3.2.4 Alginates

It is one of the water dissolvable polymers exist as hydrocolloids removed from dull shaded seaweeds. Because of its biodegradability, biocompatibility, non-antigenicity and chelating limit, alginate is commonly used for biomedical applications including tissue building, calm transport and in gastric reflux. Alginate is used to support network or transport structure for tissue fixing and recuperation. Two major sources of alginates are *Macrocystis porifera* and *Ascophyllum nodosum* (43). Alginate hydrogels can be set up through substance or potentially physical crosslinking of the polymer chains and mostly through ionic cross-connecting with multivalent cations. These gels can have water substance more noteworthy than 95% and can be heat treated without dissolving (78). Alginate is utilized in organic product texturization, the arrangement of gels, uses in protein expulsion, expansion of the capacity life of potatoes, immobilization of banana chemicals, minced fish patties, meat items, water-holding, frozen yoghurt stabilizers, dispersive capacity. Alginate has a great high fondness and restricting limit with regards to metal particles and utilized as a substantial metal adsorbent. Additionally, these are being used for the delivery of fungicides, pesticides and so forth under safe agrarian practices (79). It is also a recognized polymer by U.S. Food and Drug Administration (FDA), for different applications in recuperation remedy, food supplements, etc.

3.2.5 Carrageenan

Carrageenan is found in marine flora such as plants of family *Rhodophyceae*. Carrageenan is a nonexclusive name for a gathering of gel-moulding and viscosifying polysaccharides. Carrageenan is a sulfated polyglactin with 15 to 40% of ester-sulfate content (80). Carrageenan is a trademark regular polysaccharide (6). It is isolated from palatable red kelp development of the Rhodophyceae family, ordinarily from genera, for instance, eucheuma, solieria, cripus, agardhiella, chondrus, hypnea, sarconema, iridaea, gigartinastellate and agardhiella (6, 81), Euchema and Kappaphycusin Southeast Asia (83). It develops along the shores of North America, Europe and the Atlantic Ocean close to Britain. Also called Carrageen or Irish Moss in England, Carraigin in Ireland. To cure coughs and colds and also as gelatin carrageenan has been utilized. Carrageenan has no dietary benefit and it is used as anti-inflammatory agents (calming specialists) (7). With 40% of ester-sulfate content, carrageenan is called sulfated polygalactan. The molecular mass of carrageenan is 100 kDa. It is formed by alternative units of sugars such as D-galactose and 3,6-anhydro-galactose (3,6-AG) and these sugars are joined by α-1,3 and β-1,4-glycosidic linkage. Carrageenan has different classes, for example, λ, κ, ι, ε, μ, that contain sulfate groups about 22 to 35%. This arrangement plan was made reliant on its dissolvability in potassium chloride. The fundamental complexities of carrageenan are the number and position of ester sulfate bunches just as the substance of 3.6-AG (7). Progressively raised degrees of ester sulfate demonstrate lower dissolvability temperature and lower gel quality. Half-ester sulfate groups present in carrageenans are responsible for its chemical reactivity. These groups are basically strong anionic groups. To make them stable, carrageenans are accessible as salts of sodium, potassium and calcium. The physical properties of the carrageenans are dictated by the related cations along with the compliance of the sugar units in its polymer chain as an example, solely kappa-and iota sort carrageenans kind gels within the presence of K or metallic element ions. Acid-catalysed chemical reaction is liable for depolymerisation of carrageenans. It loses its practicality at high temperatures and low pH scale (7). carrageenin has been accounted for to possess hostile to HIV action, nevertheless its solid anticoagulant. Carrageenan is considered to be a potent inflammatory agent in rodents leucocytes to provide tumor gangrene (TNF-α) in response to microbial lipopolysaccharide (7). The immobilization of yeast cells (Saccharomyces sp.), cells of *Zymomonas mobilis*, *actinomycete aureofaciens* and *M. aurum* in κ-carrageenan for brewery production, to boost the assembly of antibacterial drug associated chlorotetracycline and for an improvement of its morpholine- degrading capability was studied. The co-immobilisation of genus *Nitrosomonas europaea* and other bacteria in κ-carrageenan was developed for element removal system (82). The essential objective of semi-refined carrageenan (SRC) creation is to expand the gel properties in alga (82). Carrageenan is employed as an associate wetting agent, binder, stabilizer, thickener, and gelling agent in food and non-food industries: trade goods (84). Carrageenan could be a feeder and used as an alternative to gelatin. In food products, carrageenan is used in human nourishment, notably in dairy farm product, like frozen dessert, milk, concentrate, milk puddings, process cheese, sweet water gels, low-calorie jellies, and baby foods; additionally as pet food (83).

3.2.6 Gum Arabic

Gum Arabic is a dried, edible, sticky exudate from the stems and components of Acacia Senegal and Acacia Seyal. These contain numerous soluble fibres (84). Acacia bushes are typically grown in arid situation for the prevention of soil erosion and to acquire gum arabic which has a range of applications. Around 900 species of acacia bushes are broadly unfolding in India, America and African sub-Sahara areas (85). Unground Acacia occurs as white or yellowish-white spheroidal tears (85, 86).

Commercially, it is on hand in the structure of white to yellowish-white flakes, granules or powder. On hydrolysis, Gum arabic's calcium, magnesium and potassium salts yield arabinose, galactose, rhamnose and glucuronic acid. It has amphiphilic facets due to the small protein component alongside the carbohydrate part. It is acidic to litmus and insoluble in alcohol. The Acacia seyal gum has low rhamnose and glucuronic acid contents and greater arabinose and 4-O-methyl glucuronic acid contents than gum from Acacia Senegal. Acacia Seyal gum consists of a moderate share of nitrogen (84, 86). Additionally, the practical attribute of gum arabic is its potential to act as an emulsifier for vital oils and flavours.

Proteolytic enzymes and prolonged heating remove the protein from gum arabic and effects in a loss of emulsification efficiency. Gum arabic (GA) is one of the most popular components extensively used in the meals and pharmaceutical industries due to its residences such as viscosity, stabilization, thickening, emulsification, vitamin and floor houses and many others (87).

The gum is used as a foam stabilizer and emulsifier. Gum arabic is extraordinarily desired in the improvement of encapsulated merchandise such as flavours, oils, bioactive elements etc. This gum inhibits flocculation and coalescence of the oil droplets. GA is a lubricant and a binder in extruded cereal snacks and low-fat cake and muffin mixes (88). GA is a hydrocolloid which is broadly used in many meals formulations to enhance fine attributes and shelf-life. Gum arabic exerts a hypoglycaemic impact (reduces the quantity of LDL cholesterol in the blood) by way of retarding glucose absorption, growing stool mass, and trapping bile acids. It has been utilized as a prebiotic dietary fibre or a non-digestible carbohydrate fibre. When GA is added to the yogurt, the viability of probiotic microscopic organisms (lactic acid microorganism and bifidobacteria) increases. Gum arabic prevents ulcerative colitis due to the fact of its trophic results on the intestine membrane and reduces the incidence of diarrhoea and its period (87, 88).

3.2.7 Gelatin

Gelatin is heteropolysaccharide present in cell dividers of herbs. Gelatin comprises of a perplexing arrangement of carbohydrate that is available in essential cell dividers and especially copious in the non-woody plant. Commercially, gelatins are obtained from citrus strips or apple pomace, that are waste biomass from juice fabricating units. Gelatin is thought to comprise basically of D-galacturonic acid (GalA) units, participating in chains by methods for á-(1-4) glycosidic linkage (89). There are additionally various examinations demonstrating the conceivable utilization of green growth for creation of biofuels (90). It is widely used as a gelling agent, to solidify the good ingredients and as a stabilizer in pharmaceutical products (91).

3.2.8 Lignin

Lignin is a characteristic complex biopolymer of starches containing polyphenolic structure in a branched network (98). Lignin is one of the parts of lignocelluloses alongside cellulose and hemicelluloses. It is obtained from farming waste, for example, rice husk, sawdust, sugarcane bagasse, corn stover etc. Lignin has a significant capacity to offer mechanical support to plant cells (3, 4). Lignin is a fortune of common fragrant natural compounds, for example, pcomaric acid (p-CA), ferulic acid (FA), syringic acid (SA), vanillin (V). Also, the lignin has different kinds of sugars, for example, rhamnose, arabinose, xylose, mannose, galactose and glucose. The lignin from non-wood biomass is composed of p-hydroxycinnamyl alcoholmonomers. p-Hydroxyphenyl subunit (H), Guaiacyl subunit (G), and Syringyl subunits (92). They are connected through, carbon-carbon linkages, and ether linkages (93). Lignin has an unpredictable cross-connecting structure like aliphatic hydroxyl, phenolic hydroxyl and methoxyl bunches inside its molecule (94). In lignocelluloses polymer, lignin typically frames ether or ester linkages with hemicelluloses which is additionally connected with cellulose (95). These lignin-based nanostructure and composites were used as antimicrobial drugs (96). Lignocellulosic biomass was also used for bioethanol production. Kraft lignin (KL), hydrolysis lignin (HL), organosolv lignin (OL) and pyrolytic lignin are the major types of specialized lignin in the trade market (97). There are two major techniques to obtain lignin from lignocellulosic biomass are basic strategy and ionic fluid technique (100). Lignin is also used for syngas production. Moreover, lignin is used as UV-sponges to remove substantial metal ions in nature. It is also utilized in medicate conveyance frameworks due to non-toxic and ecological neighborly nature (98).

3.3 Biopolymers of Microbial Origin and their applications

The various biopolymers of microbial origin and their applications are listed in Table 3 and discussed below.

3.3.1 Levan

Levan is a starch-based homopolysaccharide that contains fructose, and this spine makes the levan a one of a kind starch polymer. It has been delivered by an expansive scope of small scale life forms as exopolysaccharides (EPS) and by a predetermined number of plant species as non-auxiliary stockpiling sugars. The general properties like bio-similarity, bio-degradability, sustainability, adaptability, and eco benevolence, levan additionally offers some significant biomedical properties. Levan has strong antioxidant, hostile to cancer-causing, anti-HIV, hyperglycaemic inhibiting properties. Usage of levan in various mechanical parts made it a flexible polymer. Plant grasses in particular *Agropyron cristatum, Dactylis glomerata* and *Poa secunda* produce levan as starch storage facilities. These are generally present in stems and leaf sheaths. Wheat and grains additionally contain levan in little amounts. Other significant properties of levan are non-harmful and visual non-aggravation. Levan is reasonably heated stable with a liquefying point temperature of 225^{o}C. It is also resistant to the action of amylases and invertases (25, 52). There are some reports on microbial levan for which fructose, sugar cane syrup, glucose, molasses, glycerol or raffinose substrates were used (99).

3.3.2 Pullulan

Pullulan, is a water-soluble, neutral polysaccharide and acquired from the ageing stock of *Aureobasidium pullulans*. Pullulan is composed of maltotriose rehashing units interconnected by α-1,6 linkages. Pullulan has high glue capacity, the ability to shape strands, and biodegradable and impermeable to oxygen. Thus, pullulan has been used in blood plasma substitutes, food, glue, corrective added substances, and flocculants. *A. pullulans* additionally expends sucrose, mannose, galactose, maltose, fructose, and even horticultural squanders, for example, carbon sources. The association of hexokinase and isomerase is essential for *A. pullulans* to change over various carbon sources into the pullulan antecedent. Numerous microorganisms were reported for pullulan synthesis, including *Aureobasidium spp., Tremella mesenterica, Cytaria spp., Cryphonectria parasitica*. Pullulans (a.k.a. Pullularia pullulans) exists widely in nature including backwoods soil, ocean water, plant and animal's tissues. Pullulans is non-pathogenic; except few bacterial strain which causes disease in animals and is pathogenic to the plants (100). Pullulan can be artificially adjusted to create a polymer that is either partially soluble or insoluble in water.

3.3.3 Polylactic acid (PLA)

PLA is biodegradable thermoplastic polyester produced by polymerization of lactic acid, starch-rich precursors, corn, sugarcane or custard. PLA is advantageous than numerous oil-based polymers as bioplastic precursor. PLA was at first used for single-use bundling applications, as account for its short life cycle **(101)**. The degradation of PLA start with the lysis of ester bonds, and long polymeric chains get breakdown into shorter oligomers, dimers or monomers. In particular, the ester derivatives of PLA hydrolysed into carboxylic moiety and alcohol. These shorter units can go through the cell dividers of microorganisms and be utilized as substrates for their biochemical cycles **(102)**.

3.3.4 Poly b-hydroxybutyrate (PHB)

The common source of PHB is *Bacillus megaterium*. The bacterial PHB crystallizes to form a polymer with similar properties to polypropylene and is a biodegradable substitute for thermoplastics. The PHB is accumulated as a carbon reserve under nutrient stress conditions. The PHB was found to be part of a larger family of poly (hydroxyalkanoates) or PHAs. PHB is microbial polyester accumulated as lipoidic inclusions. In the microbial PHB, the ester bond between carboxyl groups of one monomer with an adjacent hydroxyl group. The PHB is dynamic and isotactic due to the (R) stereochemical arrangement. Separated PHB are comprehensively isolated into three classes, based on Molecular weight (MW) – (a) Low MW (b) High MW (c) Ultra-high MW PHB. Polyhydroxybutyrate can be utilized as agrarian and development materials, automobile interiors, electrical gadgets, holders, bundling materials, etc.. PHB is also used to repair body tissues, wound dressings and visual gadgets (103). *The* deficiency of nitrogen can initiate PHB biosynthesis. *Pseudomonas* sp. RZS1 accumulated a higher amount of PHB and *A. faecalis* after 30 and 24 h respectively under limited nutrient conditions. The PHB is partially soluble in chloroform, dichloroethane, trichloroethane, ethylene, hexane propanol, and methanol (104).

3.3.5 Polyhydroxyalkanoate (PHA)

Polyhydroxyalkanoate (PHA) are produced by microbes under limited growth conditions. *Ralstonia eutropha*, a model bacterium, is widely used for PHA production (105). The PHA, poly (3-hydroxybutyrate) (PHB) was first reported in *Bacillus megaterium* by the French researcher Lemoigne in 1926 (106). Polyhydroxyalkanoates is a class of linear thermoplastic polymers, belonging to bio-based bioplastic category. They can be developed through numerous microorganisms as intracellular carbon and energy stocks. Structurally, PHA are thermoplastic polyesters of hydroxyl acid (HA) monomers that are connected by an ester bond (107) PHAs are incorporated by various gram-positive bacteria, cyanobacteria and anaerobic bacteria, photosynthetic microbes and archaea. These are biocompatible, totally biodegradable, with great processability, non-poisonous and display high auxiliary diversity (108). Additionally, PHAs have been demonstrated to have antimicrobial properties against pathogens, for example, *S. aureus* Chlorhexidine (CHX), a productive antifungal operator helped through PHB/PEO strands, indicated 99–100% decrease in *E. coli* and *S. aureus*. PHAs also act as hostile to pathogens in the digestive system of mammoth, tiger, and prawn.

3.3.6 Gellan

Gellan is an anionic polysaccharide with a high atomic weight produced by *Sphingomonas paucimobilis*. Gellan gum is commercially available with the names Kelcogel, Gelrite, Phytagel and Gel-Gro. Kelcogel is utilized essentially in the food industries as a thickening and gelling agent, and also as hardening specialists, of media for culturing microbes. These properties permit its use to incorporate gellan in fluid gels (utilized in juices or fluids containing cocoa, strands, insoluble minerals), gelatin sweets and desserts, particles that immobilize yeast with applications in wine and beer production, nutraceuticals, and food supplements. The gellan blend presents gelling behaviour at lower mixing rates too. Consistency is decreased when the blend containing gellan is sheared; consequently, higher agitation rates (600-800 rpm) lead to a heterogeneous domain. It results in a significant drawback, and it causes warmth and mass exchange restrictions (109).

3.3.7 **Microbial Cellulose**

Bacterial cellulose (BC) or microbial cellulose is an exopolysaccharide produced by bacteria such as *Komagataeibacter* (previous Gluconacetobacter) in a carbon and nitrogen-enriched media (55, 110). The species of *Achromobacter, Alcaligenes, Aerobacter, Agrobacterium, Azotobacter, Gluconacetobacter, Pseudomonas, Rhizobium, Sarcina, Dickeya*, and *Rhodobacter* have been reported a significant source of bacterial cellulose (55). Komagataeibacter is used as a model organism for research and food applications, because of its higher BC yield (111). BC was reported in fermented tea which contains acidophilic bacteria and yeast (112). BC is kept as a self-preservation tool by microbes to protect themselves from the direct effect of UV (113). It has various applications in food industry preservation measures (55, 114). BC has equal molecular weight as plant cellulose, but it is free from lignin, hemicellulose and pectin which are associated in plant cellulose.

Thus, its cleaning and purification are much easier and simple as compared to cellulose of plant’s origin (115). It has higher water-holding limit (holding up to multiple times its weight in water), longer drying time and amazing ductile properties (116). BC offers a wide scope of unique applications, for example, a food framework (nata de coco), as dietary fibre, as an acoustic or channel layer, as ultra-quality paper and as reticulated fine fibre connected with covering, authoritative, thickening and suspending attributes. BC was another option and less expensive thickener as compared to Xanthan gum (XG) and insect bean gum (LBG). BC has been normally utilized for biomedical applications, for example, materials for tissue designing, injury dressing, counterfeit skin and veins, and bearers for sedate conveyance (110, 116). BC is utilized as an Immobilizer for Lactobacillus cells, securing them against gastric juices. Being food-grade, BC might be utilized as coatings for food applications, including palatable shield (117).

3.3.8 **Curdlan**

Curdlan is a water-insoluble bacterial exopolysaccharide which is delivered by *Agrobacterium* sp. under nitrogen-constrained conditions. It contains β-(1, 3)- glycosidic linkages. In correlation with some other polysaccharides, similar to cellulose and chitin, Curdlan is insoluble in water and shows astounding rheological and warming properties. It is used as a thickening tool or fat-mirror substitute in the food products (118, 119). By modifying the warming temperature, a scattered curdlan suspension in water can form different kinds of gels. The gelling properties of curdlan make it helpful for some food and non-food applications (120). Its biosynthesis happened inside the bacterial cell and emitted into the extracellular medium. Because of its astounding rheological properties, curdlan was endorsed as a food stabilizer, thickener, or texturizer (121). Curdlan is also used to improve the versatility and quality of freezable noodles. Curdlan was utilized in biomedical applications for gel exemplification. Curdlan is organic reaction modifier that improve or reestablish typical insusceptible resistances, including antitumor, against infective, mitigating, and anticoagulant properties (122).

3.3.9 Xanthan Gum

It is a thickener polysaccharide produced by *Xanthomonas campestris* mainly. The basic structure of xanthan includes repeating pentasaccharide units comprising of two D-glucopyranosyl, two D-mannopyranosyl and one D-glucopyranosyluronic unit. The thickening limit of xanthan is related to its consistency; a high thickness restricts the streaming nature of this biopolymer. Xanthan is pseudoplastic, or show shear reducing characteristics (123). Thickener (XG) is an extracellular and anionic hetero-polysaccharide discharged by gram-negative microscopic organisms including *Xanthomonas pelargonii, campestris, malvacearum* and *phaseoli* during their growth cycle (123, 124). Thickener (XG) displays an anionic character because of both glucuronic acid and pyruvic acid in the side chain (123). XG is profoundly stable to high shear pressure, warmth, acid, and it is biodegradable (124, 125). Because of its interesting techno-useful properties and remarkable compound structure, thickener shows great pseudoplasticity, thickening, rheological properties, high consistency (123). It is widely utilized in beauty care products, pharmaceutical and food definition. In food enterprises, this biopolymer has been used as a thickener, stabilizer, emulsifier and gelling agent A good yield of xanthan was obtained from *X. campestris* and *X. pelargonii* cells immobilized on Calcium alginate and calcium alginate–polyvinyl liquor boric acid (CA–PVA) (92, 93). It has capacity to conjugate with different polymers, proteins, peptides and non-peptides where these conjugates display solidness toward acidic chemicals, biocompability, and proficient solubility. Furthermore, the lysozyme–thickener conjugates could restrain the development of *Staphylococcus aureus* and Escherichia coli (124, 125).

4 Impacts of biopolymers in the circular economy

Biopolymer appeared to be costly than the oil-based plastics, yet costs have fallen as an advancement of new technologies proceeds. Costs of bioplastics thought to keep on falling as the business develops and increasingly proficient techniques are being created. Territorial financial impacts are additionally likely to change with bioplastics development. Subsequently, to minimize the transportation costs, the bioplastics plants would be fabricated nearer to the significant rural zones and urban areas of the nation. Bio-based polymers have become plausible options in contrast to customary oil-based plastics. Lately, there has been an increment in enthusiasm for the sustainable matter to be utilized in bundling, agribusiness, drug, and in different zones. Polymers structure the spines of plastic matters, and are consistently being used in a growing scope of zones. Subsequently, numerous analysts are putting time into adjusting customary issues to create them easier to understand, and into structuring novel polymer composites. Various organic materials might be joined into sustainable polymer matters, with the most widely recognized being starch and fibre extricated from different sorts of plants. The conviction is that sustainable polymer matters will decrease the requirement for manufactured polymer generation (in this way lessening contamination) with ease, along these lines delivering a constructive outcome monetarily (126). Monetary impacts of biopolymers are multidisciplinary talk utilizing equilibrium perspectives to clarify the importance and value of specific polymers to individuals. It examines the sources, types, properties and possibilities of unique polymers and furthermore considers the applications or employments of, interest and estimation of polymers to the common man. In another study titled, “Economic Impacts of Natural Polymers”, is a piece of the absolute worth logical from the presence of normal polymers, their advantage, investigate, improvement, utilization, potential for licensing commercialization, exchange and control of their assorted applications just as dispersion in nations and mainlands around the globe, particularly the West, Asia and Latin America. The estimation of natural polymers to man has been demonstrated to be boundless to the degree that they are widespread, fundamental and noteworthy life support materials. Regular polymers are known to be copious, inexhaustible, assorted, flexible, and speak to cheap wellsprings of biomaterials. In expansion, the greater part of them is biodegradable, biocompatible, safe and non-poisonous. Biomaterials dependent on regular polymers have been utilized for over 2000 years, and the logical, designing and mechanical advancement of these materials has finished into profoundly skilled labor with inventive mechanical items and administrations. Global biomaterials market was evaluated to reach US $88.4 billion, and the characteristic polymers base is outstanding. There is surprising interest in studies and assembling of various items from elastic, cotton, cellulose mash and other conventional wares, to films, plastics, the novel tissue building and nano-drug conveyance frameworks. Improved information on organic chemistry science and materials building through industrialization and commercialization is giving answers for various questions of cutting edge way of life and wellbeing requests.

5 Conclusions

Specific polymers have been developed into a few materials with applications in restorative, pharmaceutical, agrarian, nourishment and refreshments, toiletries, beautifiers, materials and other modern, local and individual consideration items. Some conventional polymers such as starch, cellulose, chitosan, alginate and gelatin have been featured by scale furthermore. Then, there are some common polymers which present day to day society needs to make due, for example, starch, wood, what's more, common elastic which are utilized for nourishment, vitality, papermaking, transportation, individually. These are notable sustainable characteristic polymer sources used in our everyday living and the absolute most significant items delivered on the planet.

The monetary ramifications of innovation and capital reliance in a world without of line and lopsided capital development and possibilities between the Less Developed Countries- LDCs and developed Countries- DCs, brings about an unbalanced appropriation of the advantages of specific polymers. This, notwithstanding market flaws furthermore, arrangements that further limit the advantages of common polymers from the rest of the world. Ecological supportability is continually expanding in significance to people, condition, and businesses, among others. In this manner, administrative bodies ought to give set down approaches for the creation and utilization of biodegradable polymers in practical condition and financial improvement.

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Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing.

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