Biopolymers , methods of synthesis and their application in food industry

Behzad mohammadi[1,*] Masoumeh Behroozian[2] Seyedeh Elaheh Jafari Sang cheshmeh[3]

[1] Department of Food Science and Technology, Afagh Higher Education Institute, Urmia, Iran.
[2] Department of Food Science and Industry, Khuzestan Faculty of Agriculture and Natural Resources, Khuzestan, Iran.
[3] Ph.D. in Food Industry - Education Director of Sima Proto Vista Research Center, Mazandaran, Sari, Iran

ABSTRACT

Food industry has been criticized for use of non-biodegradable, non-eco-friendly, and toxic production methods, materials and treatment strategies.The environmental impact of persistent plastic wastes is raising general global concern, and disposal methods are limited. The continuously growing public concern in the problem has stimulated research interest in biodegradable natural polymers. Biopolymers (polysaccharides) have various applications in medicine, food and petroleum industries. Microorganisms can produce and excrete good amount of polysaccharides in simple but costly production conditions. A number of polysaccharides produced by microorganisms have either been adopted as commercial products or have the potential for commercialization. The advent of modern biotechnology has fundamentally transformed the way scientists view organisms and the materials they produce. The main drawback limiting the development of these polysaccharides is the lack of efficient processes for their extraction and purification. However new applications in agronomy, foods, cosmetic and therapeutic could in a near future accentuate the effort of research for their development.

Keywords: Biopolymer, Plastic wastes, Production of biopolymers, Biological activities.

1. INTRODUCTION

Due to the increased production and consumption of petroleum polymers and plastics in the daily life of humans, the diseases caused by food poisoning have become a major threat to human health and the environment and have contributed to the emergence of the packaging industry. Since the bulk of the packaging industry is made up of plastics, the packaging industry can be linked to petroleum products. Therefore, the increasing growth of population, pollution caused by packaging materials derived from oil derivatives, and problems caused by various methods of disposal of these contaminations, including burning, burial, and recycling, have attracted more attention toward biopolymers and biopackaging. Biodegradable films and coatings are good alternatives to synthetic films in the packaging industry due to their eco-friendliness and low dependence on nonrenewable resources and, therefore, have attracted the attention of many researchers. Synthetic plastics that are used to pack different types of foods are causing serious environmental problems[1] Approximately 140 million tones of synthetic polymers are produced worldwide every year. Since polymers are extremely stable, their degradation cycles in the biosphere are unlimited. Environmental pollution by synthetic polymers, such as waste plastics and water soluble synthetic polymers in waste water has been recognized as a major problem. Plastics and polymers are an integrated part of our daily existence. However, because of stability and resistance to degradation, these are accumulated in the environment, at the rate of about 8% by weight and 20% by volume of the landfills[2] . Polymers are a class of “giant” molecules consisting of discrete building blocks linked together to form long chains. Simple building blocks are called monomers, while more complicated building blocks are sometimes referred to as ‘‘repeat units’. Biopolymers are defined as polymers formed under natural conditions during the growth cycles of all organisms. Therefore, they are also named natural polymers. They are formed within cells by complex metabolic processes. For materials applications, cellulose and starch are most interesting. However, there is an increasing attention in more complex hydrocarbon polymers produced by bacteria and fungi, particularly polysaccharides such as xanthan, curdlan, pullulan, chitin, chitosan and hyaluronic acid . Biodegradable polymers are growing in importance, day the day and current research is focused on producing newer biodegradable polymers. A vast number of biodegradable polymers have been synthesized or are formed in nature during the growth cycles of all organisms. Some microorganisms and enzymes capable of degrading them have been identified e.g. Depending on the evolution of the synthesis, different classifications of the biodegradable polymers have been proposed3 Primarily natural or nature-derived polymers are utilized in the food industry. These polymers can be used as films, coatings, packaging, or protective and preservative barriers. Agriculture biomass residues like zein, soy, cellulose, and starch; animal based natural polymers like collagen, gelatin, and marine food processing residues like chitosan, chitin have been used in the food industry [3], [4]Naturally obtained polymers are peculiar in determining the function (taste/biodegradability) that is to be imparted to the food either in the form of films or coating. Naturally occurring biodegradable polymers of agricultural or marine wastes, plants, or animals have been utilized to replace the conventional non-biodegradable plastic used to package food [5]. Food packaging processes derived from hydrocolloids are widely used due to their excellent barrier and mass transfer properties, due to which spoilage of the product can be delayed by increasing its shelf life. Additionally, polypeptides have a higher strength and antimicrobic action [6]. Edible nature of these films can further ensure increased uptake of nutrients by making use of composite polymer films or bioactive films that may aid in the delivery of vitamins or drugs [7]. Nanotechnology has been able to add preservatives, color, or fragrance through nanoparticles and imparts antimicrobial activity, enhanced physical and transfer abilities, and detection of pathogens. The addition of micro-and nano-fillers in the polymers can further enhance its mechano-physical properties [8]. A modern approach to providing personalized food products of desired nutrition, shape, or texture is through 3-D food printing.

1. synthesis of biopolymers

Living matter is able to synthesize a wide range of different polymers and in most organisms, these biopolymers contribute the major fraction of cellular dry matter. The functions of biopolymers are in most cases, essential for the cells and are as manifold as their structures. These biopolymers fulfill a range of quite different essential functions for the organisms such as

- Conservation and expression of genetic information
- Catalysis of reactions, storage of carbon, energy or other nutrients.
- Defending and protecting against the attack of other cells, hazardous environmental factors, sensing of biotic and abiotic factors.
- Communication with the environment and other organisms.
- Mediation of the adhesion to surfaces of other organisms or of non-living matter and many more.

All the biopolymers are synthesized by enzymatic processes in the cytoplasm, in the various compartments or organelles of cells, at the cytoplasmic membrane or at cell wall components, at the surface of cells or even extracellularly, synthesis of a biopolymer may be initiated in one part of a cell and may be continued in another part as it occurs [9].

2. Production of biopolymers

There are different ways to produce biopolymers in order to make them available for different applications:

- Many biopolymers occur abundantly in nature and are isolated from plants and algae, which grow in natural environments. Agar and alginates are isolated from red algae belonging to the genus Gelidium or from various brown algae also referred to as seaweeds.
- Few biopolymers are isolated from extremely natural sources. An example of such an exception is hyaluronic acid, which is extracted from the umbilical cords of new born children.
- In vitro synthesis of biopolymers with isolated enzymes in cell-free systems offers another possibility to produce biopolymers. One example is the application of the heat stable DNA polymerases in the

polymerase chain reaction (PCR) to produce monodisperse defined DNA molecules. Another example is dextran, which can be produced on a technical scale with isolated dextran sucrase.

- Fermentative production of biopolymers are used in industry, e. g. is polysaccharides. The biotechnological production of biopolymers may occur intracellularly or extracellularly. This causes several severe consequences regarding the limitations of the production and downstream process to obtain the biopolymers in a purified state.

3. Intracellular versus extracellular production of biopolymers

Polyhydroxyalkanoates, cyanophycin, glycogen, starch, and polyphosphate are example of biopolymers, which are accumulated in the cytoplasm of cells. The availability of space in the cytoplasm therefore limits the amount of polymer that can be produced by a cell. This is particularly relevant for fermentative production processes mostly employing microorganisms. Therefore, the yield per volume is limited/determined by the cell density and the fraction of the biopolymer in the biomass. Poly (β-Dglutamate) and many polysaccharides, such as alginates, dextran, xanthan, curdlan, pullulan, chitosan and microbial cellulose are examples of biopolymers, which occur outside the cells, either as a result of extracellular synthesis or of excretion by the cells. For these biopolymers, the volume of the bioreactor would be available to deposit the desired biopolymer. Furthermore, breakage of cells is not required and separation of the biopolymer from the other biomass is not very complex. Other strategies and the use of cell-free production processes, may take advantage of the features of extracellular processes. One strategy is to apply in vitro synthesis of biopolymers employing isolated enzymes. Another strategy is to produce the constituents of polymers as monomers by fermentative processes and to polymerize these components subsequently by solely chemical processes. Both these strategies have already entered reality and many different examples of scale have been demonstrated (i.e., not only at the laboratory scale but also at the large scale). Polylactic acid, for example has been produced on a large scale by such a combined biotechnological and chemical approach[10] .

1. Natural biodegradable polymers

Biodegradable and bio-based polymers have a wide range of applications in pharmaceuticals, medicine, horticulture, agriculture, consumer electronics, automobiles, textiles, and especially packaging. To date, many biodegradable polymers are available, such as polylactic acid or polylactide (PLA), polycaprolactone (PCL), polybutylene adipate terephthalate (PBAT), polyhydroxybutyrate (PHB), polyhydroxyalkanoate (PHA) and Polysteramide. In some cases, the high cost of producing biodegradable polymers prevents their use in replacing traditional polymers. The use of natural and renewable raw materials such as starch, lignin, collagen, cellulose as an alternative has received countless attentions.Among natural polymers, starch offers countless possibilities for the production of environmentally friendly materials with wide commercial applicability. This polymer is regenerated from carbon dioxide and water through photosynthesis in plants. Due to its ability to decompose in the environment, low cost and high regeneration ability, it can have many applications, especially in the packaging industry. So far, many efforts have been made to develop starch-based polymers in order to conserve petrochemical resources and cause less damage to the environment[11].

1.1 Biodegradable Polymers Derived from Petroleum Resources

These are synthetic polymers with hydrolysable functions, such as ester, amide and urethane, or polymers with carbon backbones, in which additives like antioxidants are added. Recent developments in this area have been reported. Synthesis, properties and biodegradability of the main classes and new families of synthetic polymers are discussed below.

1.2 Polymers with additives

Most conventional polymers derived from petroleum resources are resistant to degradation. To facilitate their biodegradation, additives are added. One method to degrade polyolefins consists in the introduction of antioxidants into the polymer chains. Antioxidants will react under UV, inducing degradation by photooxidation. Nevertheless the biodegradability of such systems is still controversial. We prefer to consider them as oxo-degradable polymers. Polyolefins are resistant to hydrolysis, to oxidation and to biodegradation due to photoinitiators and stabilizers. They can be made oxo-degradable by use of pro-oxidant additives. These additives are based on metal combinations, such as Mn^{2+}/Mn^{3+}. The polyolefin will then degrade by a free radical chain reaction. Hydroperoxides are first produced and then thermolysed or pyrolysed to give chain scission, yielding low molecular mass oxidation products with hydrophilic properties favourable to microorganisms.

2. Biodegradable polymers from fermentation

Biodegradable polymers are produced from the fermentation of polyesters and neutral polysaccharides produced by microorganisms that have access to carbon storage and energy sources. Extensive research has been conducted on PHAs, which are a group of hydroxybutyric and hydroxyvaleric acids. PHAs are high molecular weight polymers with n-alkyl substitution in the main chain. Usually, these polymers show the degree of biodegradability in the order of years. In this group, poly-3-hydroxybutyrate and polyhydroxybutyrate-co-hydroxyvalerate (PHBV) have been suggested as alternative materials for various industrial applications. The latest research in the field of PHB production shows that this substance can be obtained from water hyacinth. Water hyacinth is one of the worst aquatic weeds that is easily available and cheap. One of the most important advantages of this biopolymer is its heat tolerance, the melting point of which is around 175 degrees Celsius[12]. Biodegradable polymers made from natural materials that have been chemically modified These types of polymers include polymers such as polysaccharides, consisting of glucose and fructose units. Cell and starch have been studied more because of their potential to replace oil-based polymers on a large scale and at low cost. Starch is cheap and decomposes in nature. Therefore, it is used as an important component in bioplastics. However, the poor mechanical properties and water solubility of starches have led to the development of proposed techniques for commercial uses of this material. Currently, starch polymers have the largest market share of vegetable containers. Starch-based plastics are inherently brittle. But if they are mixed with substances such as glycerol glycol and sorbitol, they become more resistant to heat. Starch renewable plastics are generally combined with bio-renewable polymers. These types of polymers have many applications in medicine, environment and packaging industries. Starch polymers, which are biodegradable polymers made from natural materials, currently have the largest market share of vegetable containers. Starch-based plastics are inherently brittle. But if they are mixed with substances such as glycerol glycol and sorbitol, they become more resistant to heat. Starch renewable plastics are generally combined with bio-renewable polymers. These types of polymers have many applications in medicine, environment and packaging industries. Starch-based polymers are mostly used in the food industry and food packaging. The main purpose of food packaging is to protect the food, maintain the sensory, appearance and quality characteristics of the food. In the packaging industry, disposable plastic containers are used for food packaging. Many of these containers use plastic materials with different resin codes, each of which has its own advantages and disadvantages. Biodegradable polymers based on starch, which are used in disposable vegetable containers, are a suitable alternative for food packaging and overcoming these disadvantages and maintaining the advantages of old packaging.

3. Genetically engineered biopolymer production systems

Genetically engineered products are regulated on the basis of their intended use, rather than the method or process by which they are made. For example, under current Food and Drug Administration (FDA) rules, genetically engineered foods are treated the same way as conventional products. The FDA does not require that new products be approved or labeled, as long as such products are essentially similar in composition, structure, and function to food items already available on the market. However, U.S. Department of Agriculture, and Environmental Protection Agency (EPA) do regulate field tests of genetically modified plants. As of now, more than 700 permits have been granted for the field testing of genetically altered plants and other organisms[14] .

4.1 Bacterial cellulose

Cellulose is the most abundant component of biomass and the basic feedstock of the paper and pulp industries. Traditionally extracted from plant tissue (trees, cotton, etc.), cellulose can also be produced by certain bacterial species by fermentation, yielding a very pure cellulose product with unique properties. The most prevalent applications of bacterial cellulose exploit its very large surface area and its ability to absorb liquids. Consequently, very low concentrations of bacterial cellulose can be used to create excellent binding,thickening, and coating agents. Because of its thickening properties, many applications in the food industry are possible[14]

4.2 Dextrans

Dextran is the generic name of a large family of microbial polysaccharides that are assembled or polymerized outside the cell by enzymes called dextran sucrases. This class of polysaccharides is composed of building blocks (monomers) of the simple sugar glucose and is stored as fuel in yeasts and bacteria. Dextran polymers have a number of medical applications. Dextrans have been used for wound coverings, in surgical sutures, as blood volume expanders, to improve blood flow in capillaries in the treatment of vascular occlusion, and in the treatment of iron deficiency anemia in both humans and animals. Dextranhemoglobin compounds may be used as blood substitutes that have oxygen delivery potential and can also function as plasma expanders[15].

3.3 Pullulan

Pullulan is a water-soluble polysaccharide produced outside the cell by several species of yeast, most notably Aureobasidium pullulans. Pullulan is a linear polymer made up of monomers that contain three glucose sugars linked together. Pullulan compounds are biodegradable in biologically active environments, have high heat resistance and display a wide range of elasticities and solubilities. This versatility allows them to be utilized in many different ways. It can be used as a food additive, providing bulk and texture. It is tasteless, odorless and nontoxic. It does not break down in the presence of naturally occurring digestive enzymes and therefore, has no caloric content. Consequently, it can be used as a food additive in low-calorie foods and drinks, in place of starch or other fillers. Pullulan can be used as a binding agent for solid fertilizers. The biopolymer can be used as a flocculating agent for the precipitation of potash clays, uranium clays, and ferric hydroxide from slurries used in the beneficiation of mineral ores. In the medical area, pullulan acts as a plasma expander without undesired side effects. After metabolic turnover, it is completely excreted. Pullulan compounds can also serve as drug carriers, and can be used as medical adhesives. Although markets for many of the applications listed here are still relatively small, with some applications only in the exploratory stage, pullulan appears to have long-term commercial potential. In sum, pullulan’s many disparate uses may entitle it to become known as a biopolymer “wonder material”[15],[16].

3.4 Chitin and chitosan

Chitin is a skeletal polysaccharide making up a basic shell constituent of crabs, lobsters, shrimps, and insects. Chitin is widely available from a variety of sources among, which the principal sources are shellfish and crustacean waste materials. It is insoluble in its native form, although chitosan, a partly deacetylated form of chitin, is water-soluble. They are widely used in the cosmetics industry, due to their water-retaining and moisturizing capacities. Used as carriers, chitin and chitosan allow the synthesis of water-soluble prodrugs28-30. As seen above, both chitin and chitosan have similar chemical structure. Chitin is made up of a linear chain of acetylglucosamine groups while chitosan is obtained by removing enough acetyl groups (CH_3-CO) for the molecule to be soluble in most diluted acids. However, unlike plant fiber, chitosan possesses positive ionic charges, which gives it the ability to chemically bind with negatively charged fats, lipids, cholesterol, metal ions, proteins and macromolecules. Industrially, chitosan is derived from the chemical deacetylation of chitin. However, this process fails to produce chitosan of uniform quality. The process of deacetylation involves the removal of acetyl groups from the molecular chain of chitin, leaving behind a compound (chitosan) with a high degree chemical reactive amino group (-NH_2). Chitosan has attained increasing commercial interest as suitable resource material due to its excellent properties like biocompatibility, biodegradability, adsorption, ability to form films and to chelate metal ions[17].

3.5 Alginate, Pectin,

Carrageenan Sodium-alginate is derived from brown seaweed. Pectin is a complex of polysaccharides that builds lamellae plant cells .Carrageenan is extracted from red seaweed. Alginate and pectin films can be formed by dipping the supporting plate into aqueous alginate, while low-methoxyl pectin solutions produce films followed by ionic crosslinking with a calcium salt and drying. Carrageenan films are formed when warm neutral or alkaline solutions are cooled. When the gel is formed, they are dried under specific conditions. Since they are dissolvable, these films have weak mechanical properties. They are not moisture-resistant. Carrageenan films are good barriers for oxygen and lipids; they prevent fat oxidation in products. Films from this group are used as an edible coating for fruit, vegetables, cheese and meat products. Alginates are used as natural binders in coating paper to produce surface consistency[18] noticed that products coated in alginate films were losing less water.

4. Biopolymers for Food Applications

Food biopolymers are divided into two categories: polysaccharides and proteins. Proteins are amino acid polymers found in plant and animal tissues. Shear, heat, and pH all affect the structural stability of proteins in meals. Polysaccharides, which are branching or linear polymers of sugars bound by glycosidic connections, constitute a significant source of energy in nature. Endo and exo core matrices of marine species and plants include polysaccharides as a hydrated compound. Biopolymers, as part of specialized structures with qualities, are currently widely used in food processing due to their capacity to interact with the other food components to increase their physicochemical properties and stability. Monosaccharides of identical or distinct residues are used to make polysaccharides. They are a visually attractive food packaging platform. Active packaging, composed chiefly of polysaccharide biopolymers, protects food against pathogenic and spoilage germs. Food components undergo phase transformations during preparation and storage at different temperatures and pressures (liquid-gel or liquid-solid). These alterations have an impact on food quality and stability. This is because changes in the physical characteristics of meals are connected to phase transitions in food components [19]. Food phase transition has been emphasized to enhance goods and processes by controlling the process. In recent years, there has been a lot of research on the design and qualities of fat-replaced food items. Biopolymers, particularly hydrocolloids, are often employed to replicate lipids' sensory and rheological qualities in these food systems.

5. Microbial Polysaccharides in Food Industry

Several polysaccharides are water-soluble gums generated by a diverse range of microorganisms that have innovative and distinctive features. Due to their low cost, these biopolymers have evolved into unique and industrially relevant polymeric compounds. Microbial polysaccharides offer a wide range of uses in the food business due to their structural and physicochemical diversity . They are used as stabilizers, emulsifiers, gelling agents, binders, coagulants, and suspending agents. The distinctive rheological qualities of these biopolymers are due to their regular structure and high purity, making them ideal for the food industry. Microbial polysaccharides are non-toxic, biodegradable, and environmentally benign, and they stay active at high temperatures, pH, and salinity. These are suitable substitutes for natural water-soluble gums and synthetics. Due to their superior properties, they may prove to be novel polymers in the food industry as suspending, thickening, and gelling agents. Using genetically engineered microbes under-regulated fermentation settings might lead to the synthesis of new exopolysaccharides with improved characteristics, thus opening up new industrial uses. Polysaccharides can be heteropolymers, or homopolymers, having neutral (pentoses and hexoses) or anionic (uronic acid) sugars, with or without connected non-sugar molecules. As texturizers, thickeners, stabilizers, and gelling agents, microbial polysaccharides improve the flavor, quality, and texture of food [20].

6. Packaging Materials

Plastic materials obtained from oil (such as polyolefins, polyesters, polyamides, polyethylene, polyvinyl alcohol, rubber latex, fluorocarbons, etc.) are used for food packaging. These polymers are cheap and available. They have good mechanical properties (such as tensile and tear strength), they are good barriers for oxygen and vaporizable aromatic substances, and they can be hot welded. Contrastingly, plastic materials are not permeable to water vapor, and they are not biodegradable, which means that they are not environmentally friendly. That is the reason why application of plastic materials must be limited and gradually replaced by other materials that cause fewer ecological problems. The shelf-life of food products can be widely extended if edible casings and coatings made of polysaccharides, proteins and lipids are applied. They are good barriers for the transfer of gasses and water vapor. Consumers want to purchase products that contain biodegradable materials.

They want to purchase high-quality products too. They are concerned about environmental problems caused by the disposal of non-renewable food packaging materials. They are interested in the use of renewable raw materials for food packaging and they are willing to increase usage of agricultural by-products. The application of edible films in food packaging has been studied by a great number of scientists around the world. Application of these films enhances the quality and safety of food products, as well as extending their shelf-life [21]. Films made from biopolymers work as barriers against the diffusion of moisture, gasses and vaporizable aromatic materials; they can carry a great number of additives (such as flavoring agents, antioxidants, vitamins, colorants, etc.) Biodegradable films can contain different antibacterial agents: nisin, lysozyme and organic acids (benzoic, sorbic, propionic, and lactic acid). They are used in the production of various food products (such as cheese and meat products). This is the best way to preserve food and stop its deterioration.

7.1 Antimicrobial Films and Active Packaging

Food poisoning, particularly of the sort that has happened over the last few decades, has raised our awareness of the need to discover new procedures to inhibit the growth of microorganisms to protect food safety and quality. One of the latest ways to preserve food is to apply antimicrobial films to the surface of a product. Several studies show that antimicrobial films and coatings are very efficient in reducing the level of such pathogen microorganisms as Escherichia coli O157:H7, Listeria monocytogenes, Salmonella Typhi and Staphylococcus aureus .Different matrixes are used to incorporate antimicrobial agents (for example, proteins, lipids, polysaccharides or composites). Organic acids, enzymes, bacteriocins, peptides, polysaccharides and essential oils are incorporated into polymer coatings as antimicrobial agents. The great benefit of antimicrobial edible films is that they may be used as inhibitors. They affect potential polluters on the surface of a product, and prevent their penetration inside the product. Polysaccharides, such as chitosan, for examples, create strong films that can carry high levels of antimicrobial agents. Chitosan films that are made of hydrochloric, formic and acetic acids are hard and brittle, while films that are made of lactic or citric acids are soft and elastic, which enables the production of multilayer coatings and wrappers. Coma et al. (2002) discovered that chitosan wrappers which contain 1% of acid inhibit L. monocytogenes and L. Innocua if we apply them onto the surface of cheese. The existence of an L. innocua population on the surface of cheese was 10 times higher in chitosan-free samples than in chitosan-coated samples[22].

7.2 The Influence of Biopolymeric Materials on the Environment

Interest in the production of biodegradable materials has been growing recently. The reason for this is increased awareness of the problems caused by the disposal of conventional synthetic plastic materials derived from petroleum. The greatest usage of plastic in the world today is in the packaging of food, owing to the combined fact that petroleum-derived plastic materials are available in large quantities at low cost and that they have favorable functional characteristics. But it takes a long time to degrade plastics and other types of food packaging products harmful to the environment. The food packaging industry is putting a lot of effort into reducing the amount of waste they produce, which is where biopolymeric materials come in, as it has been shown that they can have a positive effect on the environment. Many countries have developed standards which define the quality and properties of biomaterials, first and foremost biodegradability. These standards initiate the reduction of waste, especially food packaging waste. Application of biopolymers in food production, processing and preservation contributes to environmental protection: the use of raw fossil materials is reduced while the biodegradability of new raw materials is increased. Application of biomaterials reduces global warming. Application of biomaterials in food packaging has a social dimension that plays a significant role in preserving the quality of fresh products and extending the global food market. Thus, biomaterials and nanotechnology are becoming increasingly more accepted in the food industry and especially in the manufacture of packaging materials. Consumers constantly demand products with specific physical and chemical characteristics, as well as functional foods. Production of such food requires the implementation of food components with different bioactivity characteristics. Use of classical technologies for the production of functional foods with the sort of characteristics being demanded is insufficient. Biomaterials, with their inherent bioactivity and nano size (1–10 μm), are easier to implement in food products. Nano-sized particles increase the solubility, stability and availability of components. Use of nanotechnology will only increase in the years to follow. However, having in mind all of the positive characteristics of biomaterials, one must also consider the potential health effects[23].

7. CONCLUSION

Industrial interest in biopolymer has steadily increased over the decades. The demand for new materials from future manufacturers of biopolymers is overwhelming. However, the material's cost-effectiveness needs to improve as it is explicitly made available for sustainable development. Bio-based polymers are closer than ever to traditional polymers. Today, with advanced research and development in biotechnology and public awareness, bio-based polymers are commonly found in various applications, from consumer goods to high-tech applications. Food packaging plays an essential role in protecting food from external contamination and maintaining quality, integrity, and safety throughout its shelf life. Materials based on synthetic polymers are used primarily as packaging materials in the food industry due to their ease of manufacture, versatility, affordability, functionality, lightweight, flexibility, and low cost. However, these synthetic polymers are not degradable, and most plastic scraps and debris pollute the environment badly. This requires the development and use of biodegradable polymer materials to solve these environmental problems. Biopolymers or renewable resource-based biopolymers include carboxymethyl cellulose, hemicellulose, pectins, carboxymethyl cellulose, starch, xanthan gum, pullulan, etc. Alginate, guar gum, gum karaya, agar, and gellan, etc., have great potential to replace traditional petroleum-based food packaging materials. The use of biopolymers, such as PLA silk and chitosan are increasingly being explored for medicine applications. The unique properties of biopolymers, such as biocompatibility and biodegradability, offer significant benefits and increase their potential .

REFERENCES

[1] Mohammadi, B., Pirsa, S., & Alizadeh, M. (2019). Preparing chitosan–polyaniline nanocomposite film and examining its mechanical, electrical, and antimicrobial properties. *Polymers and Polymer Composites*, *27*(8), 507-517.

[2] Rao, M. G., Bharathi, P., & Akila, R. M. (2014). A comprehensive review on biopolymers. Sci. Revs. Chem. Commun, 4(2), 61-68.

[3] Gupta, I., Cherwoo, L., Bhatia, R., & Setia, H. (2022). Biopolymers: Implications and application in the food industry. Biocatalysis and Agricultural Biotechnology, 102534.

[4] Iñiguez-Moreno, M., Ragazzo-Sánchez, J. A., & Calderón-Santoyo, M. (2021). An extensive review of natural polymers used as coatings for postharvest shelf-life extension: Trends and challenges. Polymers, 13(19), 3271.

[5] Mangaraj, S., Yadav, A., Bal, L. M., Dash, S. K., & Mahanti, N. K. (2019). Application of biodegradable polymers in food packaging industry: A comprehensive review. Journal of Packaging Technology and Research, 3, 77-96.

[6] Yang, Y., Cai, Z., Huang, Z., Tang, X., & Zhang, X. (2018). Antimicrobial cationic polymers: From structural design to functional control. Polymer Journal, 50(1), 33-44.

[7] Chen, W., Ma, S., Wang, Q., McClements, D. J., Liu, X., Ngai, T., & Liu, F. (2022). Fortification of edible films with bioactive agents: A review of their formation, properties, and application in food preservation. Critical Reviews in Food Science and Nutrition, 62(18), 5029-5055.

[8] Collazo-Bigliardi, S., Ortega-Toro, R., & Boix, A. C. (2018). Isolation and characterisation of microcrystalline cellulose and cellulose nanocrystals from coffee husk and comparative study with rice husk. Carbohydrate polymers, 191, 205-215..

[9] Asada, Y., Miyake, M., Miyake, J., Kurane, R., & Tokiwa, Y. (1999). Photosynthetic accumulation of poly-(hydroxybutyrate) by cyanobacteria—the metabolism and potential for CO2 recycling. International journal of biological macromolecules, 25(1-3), 37-42.

[10] Rao, M. G., Bharathi, P., & Akila, R. M. (2014). A comprehensive review on biopolymers. Sci. Revs. Chem. Commun, 4(2), 61-68.

[11] Ghanbarzadeh, B., & Almasi, H. (2013). Biodegradable polymers. Biodegradation-life of science, 141-185.

[12] Luckachan, G. E., & Pillai, C. K. S. (2011). Biodegradable polymers-a review on recent trends and emerging perspectives. Journal of Polymers and the Environment, 19, 637-676.
[13] Lee D, Powers K and Baney R. Physicochemical properties and blood compatibility of acylated chitosan nanoparticles. Carbohydr Polym 2004; 58: 371–377.
[14] Kurdikar, D., Fournet, L., Slater, S. C., Paster, M., Gruys, K. J., Gerngross, T. U., & Coulon, R. (2000). Greenhouse gas profile of a plastic material derived from a genetically modified plant. Journal of Industrial Ecology, 4(3), 107-122.
[15] Liu, P., Shi, B., Yue, C., Gao, G., Li, P., Yi, H., ... & Cai, L. (2013). Dextran-based redox-responsive doxorubicin prodrug micelles for overcoming multidrug resistance. Polymer Chemistry, 4(24), 5793-5799.
[16] DeSimone, J. M. (1973). Japanese develop starch-derived plastic. Chem Eng News, 24, 40.
[17] Pirsa, S., & Mohammadi, B. (2021). Conducting/biodegradable chitosan-polyaniline film; Antioxidant, color, solubility and water vapor permeability properties. Main Group Chemistry, 20(2), 133-147.
[18] Kester, J. J., & Fennema, O. R. (1986). Edible films and coatings: a review. Food technology (Chicago), 40(12), 47-59.
[19] Moraga, G., Talens, P., Moraga, M. J., & Martínez-Navarrete, N. (2011). Implication of water activity and glass transition on the mechanical and optical properties of freeze-dried apple and banana slices. Journal of Food Engineering, 106(3), 212-219.
[20] Jindal, N., & Khattar, J. S. (2018). Microbial polysaccharides in food industry. In Biopolymers for food design (pp. 95-123). Academic Press.
[21] Auras, R., Harte, B., & Selke, S. (2004). An overview of polylactides as packaging materials. Macromolecular bioscience, 4(9), 835-864.
[22] Coma, V., Martial- Gros, A., Garreau, S., Copinet, A., Salin, F., & Deschamps, A. (2002). Edible antimicrobial films based on chitosan matrix. Journal of food science, 67(3), 1162-1169.
[23] Arif, Z. U., Khalid, M. Y., Sheikh, M. F., Zolfagharian, A., & Bodaghi, M. (2022). Biopolymeric sustainable materials and their emerging applications. Journal of Environmental Chemical Engineering, 10(4), 108159.