Environment, Development and Sustainability
https://doi.org/10.1007/s10668-023-03756-2

REVIEW

# Substantial utilization of food wastes for existence of nanocomposite polymers in sustainable development: a review

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Received: 9 March 2023 / Accepted: 3 August 2023


## Abstract

The problem of food disposal has grown more serious, but the application of nanocomposite polymers offers a viable solution. These cutting-edge polymers provide cost-effective solutions and a sustainable means of reducing environmental harm. Food waste can be used extensively to make nanocomposite polymers, that are useful in a variety of industrial applications. Biodegradable components like lignin and chitin, which are sourced from animal products or crop leftovers, are used to create the cutting-edge polymers. The mechanical qualities and endurance of the polymers are improved by including these natural components, making them suitable for a variety of industrial fields. In the rapidly expanding sector of biocomposite polymer materials, there is a big emphasis on using food waste as a viable feedstock. According to research, biocomposites made from food waste have better mechanical strength and barrier qualities than conventional materials. These biocomposites can also be modified to fulfil specific application requirements, such as better thermal insulation capabilities or higher fire resistance. They are a desirable replacement for conventional synthetic polymers due to their sustainability, which also expands the variety of possible uses. Inorganic and organic nanoparticles are mixed with biopolymers to form nanocomposite materials based on biopolymers. While many waste materials can be employed as substrates for the manufacture of bionanomaterials, recent focus has been placed on the food industry waste, which is produced at a significant pace globally. These biopolymers are gaining popularity in the pharmaceutical and medical industries in addition to their current use in culinary applications because of their distinctive properties. This study sheds light on the possibilities of this novel strategy for sustainable development by compiling a wide range of food waste sources and biopolymer synthesis technologies.

**Keywords** Biocomposites · Biodegradable · Biopolymer · Waste utilization · Food waste

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Published online: 25 August 2023

## 1 Introduction

In food industries, the agriculture sector and in houses, food waste is a prevalent issue. Such wastes build up and cause more environmental contamination, and unintentional landfilling of these wastes may reduce rainwater infiltration. Food waste cannot be prevented, it is possible to recycle and creatively repurpose agricultural and industrial wastes in the form of biopolymers. This direction can be moved in part by altering how much food is wasted and lost globally (Ezeoha et al., 2013). Sources of food squandering would include the food industry and post-harvest agro processing, which endangers the surroundings both before and after businesses. These leftovers are frequently dumped in landfills or used to make manure. However, according to Theagarajan et al. (2019) creating value-added items from this bio-waste and reprocessing them into marketable commodities will not only promote eventual outcomes but also increase earnings for a commercial platform in terms of economy. It has been noted that geographical characteristics influence how much food waste is dumped worldwide. One interesting feature is that established countries like the EU and the USA, in addition to developing India are also a part of garbage production. This includes accountability on the part of a component of these nations to more effectively utilize the waste materials to lessen the current bio burden both things may require practise and measures that would lessen the waste load (Kulkarni & Anantharama., 2020). Biopolymers, which are made up of large non-polymeric structures such as macromolecules and lipids as well as nucleic acids, carbohydrates, proteins, and lipids, are significantly more common macromolecules, according to (Baranwal et al., 2022). The Greek terms "bio" and "polymer," which depict natural and living creatures, are the source of the phrase "biopolymer." Biopolymers are macromolecules consisting of large number of monomer units. A solitary monomer is defined as a macromolecule by IUPAC (Morganti et al., 2022). The biopolymers are discovered to be highly biocompatible, rendering them helpful in numerous applications, including edible coatings, emulsification, plastic packaging, and surgical devices including organs, wound healing, tissue scaffolds, and dressing materials in the pharmaceuticals sectors. Examples of synthetic macromolecules include plastics, artificial fibres, and research materials such as nanomaterials (Baranwal et al., 2022).

Recently, biopolymer food packaging is creating a sensation in the market. It is possible to increase the functional performance of biopolymer-based packaging materials by adding active ingredients to increase food safety and shelf life, such as antimicrobials or antioxidants ("active" packaging), or by adding sensors to monitor the condition of packaged foods ("smart" packaging) (Sani et al., 2021). Sensors found in smart packaging materials often offer data on the quality, freshness, or safety of food. These sensors frequently react when the pH, content, or temperature of food changes while it is being stored (Alizadeh-Sani et al., 2021). Their structural infrastructures may include a range of organic and inorganic side groups that help the molecules operate in addition to repeating units of nucleic acids, amino acids or saccharides. Polyhydroxyalkanoates (PHAs) and polylactic acid are some examples of biopolymers found in microbes or genetically engineered organisms using conventional chemical techniques (PLA). These include cellulose-derived carbohydrates and antibodies from milk or collagen. The gene editing of microbes enables the biotechnological synthesis of biopolymers with tailored characteristics suitable for higher-value biomedical applications, like drug delivery and tissue engineering. The classification of biopolymers is mentioned in Fig. 1.

According to Basumatary et al. (2022), extrusion, layer-by-layer construction, and solution casting are three primary fabrication techniques for biopolymer-based nanocomposite

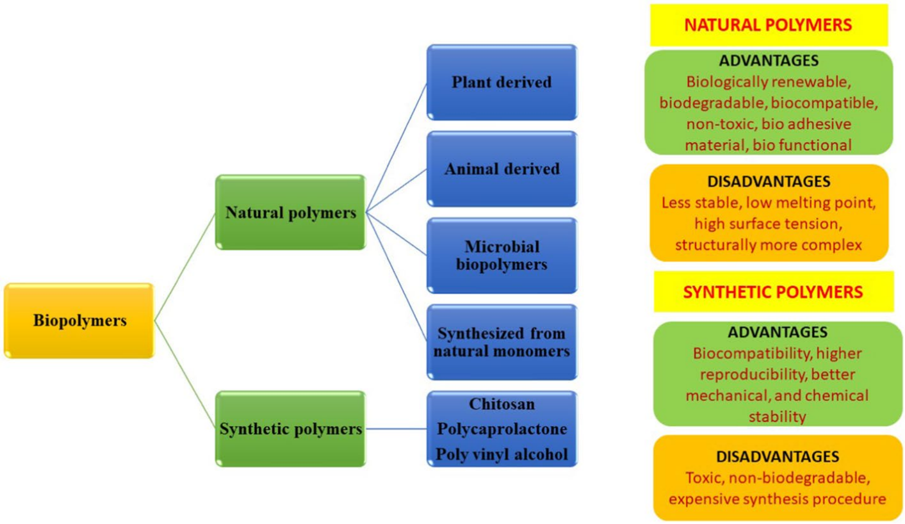


**Fig. 1** Classification of biopolymers according to their original place

films. The basic fabrication methods for biopolymer-based nanocomposite films are extrusion, layer-by-layer, and solution casting (Basumatary et al., 2022). A straightforward method for creating blended nanocomposite films is solution casting. Applying coatings on the surfaces of fruits and vegetables involves smearing, spraying, dipping, or submerging food ingredients with nanocomposite solutions. The coating process entails a number of steps, including the formation of raw materials using an appropriate ratio of biopolymers and active ingredients or nanomaterials, the formation of the coating solution by mixing, irradiating, heating, and/or steam flash pasteurizing, the disinfection of food samples—typically by dipping them in sodium hypochlorite solution—the application of composite solutions to create uniform coatings on food, drying, and then packaging and storage in the proper conditions. Food waste through diverse industrial, agricultural, and domestic sources has significantly increased because of the fast rise of the world's population and changes in lifestyle. Every year, over one-third of the food produced, is thrown away, severely depleting resources. The correct management of food waste is a pressing worldwide issue because it includes abundant organic materials that, if not controlled effectively, can constitute a major danger to the environment and public health (Liu et al., 2023). Different kinds of food scraps, like waste from the cultivation and preparation of fruit, vegetables, grains, and other foods, contain vital bioactive substances like polyphenols, dietary fibre, proteins, lipids, vitamins, organic acids, and minerals, some of which are present in higher concentrations in the parts that are thrown away than in the parts that are sold. These bioactive substances have the capacity to transform food waste into commodities with additional value. The opportunity for using waste from the food industry as the major or secondary fuel for the manufacture of biopolymers by extraction or fermentation, either with or without pre-treatment by solid-state fermentation to generate fermentable sugars, is quite high (Ranganathan et al., 2020a, b). Nanocomposite is added as an augmentation to biopolymers to enhance their barrier, physical, thermal, and functional properties. To generate biopolymer-based nanocomposite materials, inorganic and organic nanoparticles are mixed with biopolymers. In instance, in contrast to traditional microfillers, nanostructures can have greater specific surface areas, surface energies, and densities. These characteristics might result in polymers with novel and enhanced properties because of synergistic effects that are superior to those brought about by the simple rule of combinations. Bionanocomposites are therefore favourable for a variety of programmes, including pharmaceutics, cosmetics, food packaging, forestry, agriculture, electronics, transportation, and infrastructure (Idumah et al., 2021). Active substances including anti-browning and antioxidant agents, colourants, nutrition, taste, and antibacterial compounds can be effectively transported by biopolymer frameworks. These bioactive components improved the bionanocomposite materials' capabilities, making them suitable for use as proactive food packaging. The nanofiber materials made of biopolymers can be constructed as oxygen scavengers, moisture absorbers, ethylene absorbers, ethanol emitters, and taste-absorbing/releasing components (Basumatary et al., 2022). Certain characteristic features of biopolymers are mentioned in Table 1.. This review summarizes the in-depth knowledge regarding biopolymers, different components that can act as biopolymers, and their application in various domains. Investigating the possibility of employing food waste as a raw material for the creation of nanocomposite polymers is the goal of exploring the significant utilization of food wastes for the existence of nanocomposite polymers in sustainable development. The intent of the review is to examine the characteristics and manufacturing processes of nanocomposite polymers produced from food debris. The study would also concentrate on evaluating the sustainability and environmental impact of these nanocomposite polymers in comparison with conventional packaging materials.

## 2 Elements of food wastes for biopolymers production

### 2.1 Cellulose

The linear polymer known as cellulose is made up of d-glucopyranose units connected by 1,4-glycosidic linkages. The original polymer has a large molecular weight and can occasionally reach a degree of polymerization of 10,000. It is also rather rigid, with a persistence length calculated by molecular modelling to be around 15 nm (or around 30 d-glucopyranose residues). Because the sugar rings are rather rigid, cellulose and polysaccharides in general are flexible due to conformational freedom around the glycosidic linkages, which is often characterized by the (varphi) and (psi) torsional angles (Hadimani et al., 2023). A cellulose polymer can create intramolecular hydrogen bonds between consecutive glucose units because its hydroxyl groups are equatorially positioned. These bonds can be made between the hydroxyl group on $C_3$ and the ring oxygen ($O_3H_3O_5$) and between the hydroxyl groups on $C_2$ and $C_6$, respectively ($O_6H_6O_2$ or $O_2H_2O_6$). Due to the molecule's structure, these hydrogen bonds can only develop if two glucose units are twisted $180^0$ in relation to one another around the chain axis to reach a 21-fold (or close to) conformation. In both the solution and solid states of water-soluble cello oligomers, this conformation is in fact the dominating one (Wohlert et al., 2022). These natural polymers are extremely crystal and have significant molecular weights due to the inter- and intra-bonding between the hydrogen atoms. The origin of the household waste and the technique of preparation affect the structural alterations and crystallinity of cellulose. The richest producers of cellulose are discovered to be grain straw, rice, mango seed, citrus peels, peanut husk, and peanuts. Glass fibre is frequently substituted with cellulose in the production

**Table 1** Characteristics of various nanocomposites based on plants, animals, and microbial organisms

| Sr. no. | Nanocomposite | Characteristics | References |
|---|---|---|---|
| *Plant-based biopolymer Nanocomposite* | | | |
| 1. | Wheat gluten (WG) nanocomposites | WG has weak mechanical characteristics and reduced resistance to penetration by water and gases. | Diao et al. (2014) |
| | | A WG nanocomposite film with enhanced hydrophobicity, mechanical, and antibacterial properties was created by casting glycerol, cellulose nanocrystals (CNC), and TiO2 nanoparticles. | El-Wakil et al. (2015). |
| 2. | Soy protein-based nanocomposites | Combining soy protein with other organic polymers to improve its moisture sensitivity and mechanical qualities blending with biopolymers like cellulose and starch. | Chinma et al. (2012), Koshy et al. (2015) |
| | | The presence of gelatin and/or other proteins guarantees the "biodegradability" of the final blended films. | Guerrero et al. (2011), Li, Jin, et al. (2017). |
| | | According to numerous researches, adding nanocellulose and cellulose nanofibril (CNF) to SP improves the tensile strength, water vapour barrier, and light barrier properties of the nanocomposite films. | Li, Jin, et al. (2017), Xiao et al. (2020) |
| 3. | Carnauba wax-based nanocomposites | In Indian jujube (plum), it was discovered that carnauba wax was effective in lowering weight loss, respiration rate, ethylene production, and flesh softening during post-harvest storage at 20 C. | Chen, Sun, et al. (2019) |
| 4. | Agar nanocomposites | Agar nanocomposite film with Zn and Cu minerals demonstrated better mechanical, optical, and thermal properties. | Wang and Rhim (2015) |
| | | The functionality of the film was also affected by the addition of Zn and Cu minerals to the agar. For use in food packaging, agar blends with alginate, collagen, or carrageenan that also contain silver nanoparticles and grapefruit seed extract (GSE) were produced.<br>According to their findings, the ternary nanocomposite film can be utilized to package highly respiring fresh product in a way that is both antifogging and actively antibacterial. | Malagurski et al. (2017), Radovanovic et al. (2019) |

**Table 1** (continued)

| Sr. no. | Nanocomposite | Characteristics | References |
|---|---|---|---|
| 5. | Starch nanocomposites | The properties of starch-based films and coatings vary greatly depending on their botanical source and manufacturing environment.<br>In order to increase versatility and improve functionality when creating films for use in coating and food packaging, starch is frequently changed. | Lopez-Cordoba et al. (2017) |
| *Animal-based biopolymer nanocomposite* | | | |
| 1. | Chitosan nanocomposites | Chitosan has inherent antimicrobial and antioxidant properties. Several nanomaterials and plant-based active components have been used to further improve its antimicrobial and antioxidant activity. | Kumar et al. (2018) |
| | | In addition, the nanomaterials also improve physicochemical properties such as mechanical, barrier, and optical properties of the chitosan nanocomposites.<br>The composite coating of chitosan and Aloe vera gel treatment delayed the ripening process and extended the shelf life of tomatoes up to 42 days. | |
| | Gelatin nanocomposites | At 40 C, gelatin dissolves in aqueous solutions, which cool to produce thermo-reversible gel.<br>The hybrid film's water resistance, mechanical strength, and antibacterial characteristics are all improved by blending gelatin with chitosan. | Etxabide et al. (2017) |
| | | In this regard, our research group produced a hybrid nanocomposites film of chitosan, gelatin, and AgNPs for active packaging of black grapes. | Kumar et al. (2017) |
| | Whey nanocomposites | For the past 20 years, WP-based coatings and films have been tested for their ability to preserve fruits and vegetables. | Cisneros-Zevallos and Krochta (2003). |
| | | When flaxseed oil and beeswax were added to WPI-based film, the film's plasticizing and water vapour barrier qualities improved. | Reinoso, Mittal, and Lim (2008). |
| | Casein nanocomposites | Due to its water resistance, it is used in many industrial applications.<br>Casein-based films and coatings have been improved mechanically and functionally by blending with other biopolymers. | Chevalier et al. (2018) |
| | | Nanomaterial-reinforced casein-based nanocomposites enhance the mechanical, barrier, and antibacterial characteristics. | Wang et al. (2017) |

**Table 1** (continued)

| Sr. no. | Nanocomposite | Characteristics | References |
|---|---|---|---|
| *Microbial biopolymer nanocomposites* | | | |
| | Dextran nanocomposites | The first commercially successful microbial exo-polysaccharide was dextran, and Leuconostoc mesenteroides is the most popular bacteria for using in industrial manufacture of the biopolymer. | |
| | | Due to its hydrophilicity, biocompatibility, and low toxicity, dextrans are frequently utilized as additives in food, pharmaceuticals, cosmetics, and clinical applications. | |
| | | In food applications, dextrans are used as a stabilizing ingredient in confectionery items, a texturizing agent in puddings and gluten-free bread, a crystallization inhibitor in ice cream, a moisture retention agent, and a viscosifier in food pastes. | |
| | Xanthan nanocomposites | Xanthomonas campestris is the most frequent producer of xanthan, a microbial exo-polysaccharide (EPS), which was primarily commercialized as a water-soluble gum. Since the 1970s, it has been used as a regulated and safe food ingredient (gum) in cheese, dressing, syrups, and sauces. | Melo et al. (2011) |
| | | Films and coatings have been applied using xanthan alone or in conjunction with other biopolymers including starch and gelatin. | |
| | | According to several studies, xanthan gum enhances the mechanical characteristics and water vapour barrier of these films or coatings. | |
| | Bacterial cellulose nanocomposites | The fact that bacterial cellulose is fully pure—that is, free of other biogenic substances like lignin and pectin—is one of its greatest advantages. | Esa, Tasirin, and Rahman (2014) |
| | | In order to broaden the range of uses for bacterial cellulose-based nanocomposite films and coatings in food packaging and preservation, substantial research has been conducted on these materials. | Lin et al. (2013) |
| | | By adding graphene oxide-copper oxide nanohybrids, bacterial cellulose-based nanocomposite has been found to have better antibacterial capabilities. | Xie et al. (2020) |

**Table 1** (continued)

| Sr. no. | Nanocomposite | Characteristics | References |
|---|---|---|---|
| | Polyhydroxyalkanoates nanocomposites | Numerous bacteria, including Alcaligenes, Azotobacter, Pseudomonas, and recombinant Escherichia coli, produce polyhydroxyalkanoates (PHAs), which are polymers of hydroxyalkanoates (HAs). | Khanna and Srivastava (2005) |
| | | Methylotrophs use carbon from renewable sources including sugar, starch, alcohol, and business waste like molasses and fatty acids.<br>Due to its recyclability, biodegradability, and water vapour barrier qualities, PHA-based films and coatings have generated interest for use in food packaging applications.<br>The PHA-based nanocomposites with Ag, Au, ZnO, and/or TiO2 nanoparticles demonstrated effective antibacterial activity against pathogens that cause food poisoning and microorganisms that cause rotting. When PHA-based nanocomposites were impregnated with natural plant extracts like vanillin, bacteriocins like pediocin, and essential oils like eugenol, similar antibacterial properties were observed. | Chanprateep (2010) |

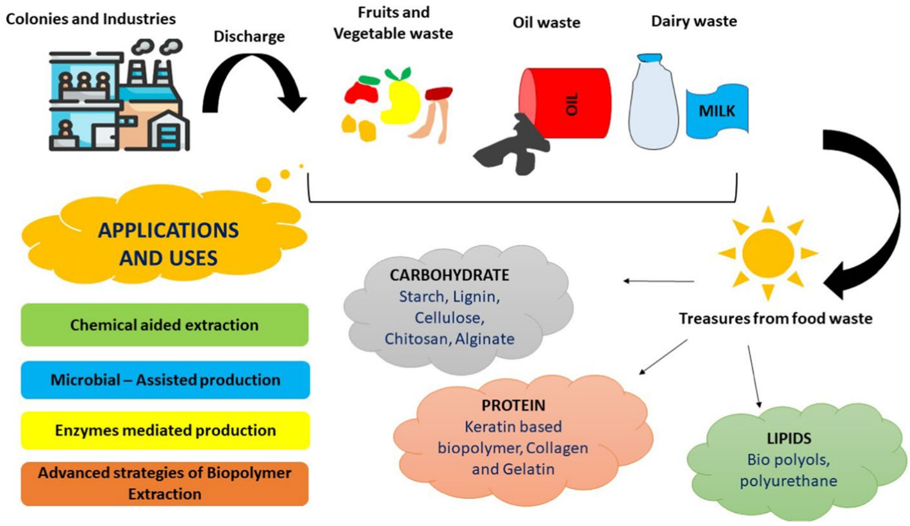


**Fig. 2** Sources of waste utilized in biopolymer production

of thermosetting and thermoplastic polymers (Sharmila et al., 2020). Different types of sources from are mentioned in Fig. 2.

## 2.2 Starch biopolymer

Starch is a naturally occurring, biodegradable and renewable carbohydrate that is formed by photosynthesis in plants and is widely distributed in their roots, stalks, and seeds. Starch is commonly used raw materials in the industry for paper, textiles, plastic, glue, and everyday items because it is among abundant commodities throughout the world. (Han et al., 2020). Khan et al. (2017) supported that amylose, a sequential polymer, and amylopectin with the same basic framework as amylose, make up the polysaccharide known as starch. Starch is a semicrystalline polymer that is widely distributed in tubers including potato, cassava, and tapioca along with cereal grains including wheat, rice, and maize (Dang et al., 2023). Because it is inexpensive, widely accessible, and environmentally friendly, starch has gained attention as an efficient material for food packaging applications. The properties of starch-based coatings and films differ considerably based on their botanical source and manufacturing environment (López-Córdoba et al., 2017).

To increase flexibility and improvise effectiveness when creating films for use in covering and food packaging, starch is frequently changed. Cross-linking or reinforcing has been one of the best technologies to use to enhance a material's physiochemical and operational qualities Dufresne et al., (2017). Additionally, CNFs show enormous potential as a substrate for starch-based nanocomposite reinforcement. In order to create novel nanocomposites, banana starch describes the design and implementation of CNF (obtained from banana peels) using solution casting a way (Pelissari et al., 2017). According to their findings, the CNF-reinforced nanocomposites outperformed the pure starch sheet in terms of tensile strength, Young's modulus, heat along with water resistance. Substantial connections among CNFs and indeed the starch substrate result in complex network structures in the CNF-reinforced nanocomposite films, which significantly increase mechanical, water shield, and UV light non-permeability. The hydroxyl groups in starch are replaced by other chemical groups during esterification or etherification, therefore leading to deterioration receptivity of water molecules. Combining starch with other biopolymers is a strategy that has demonstrated considerable improves crystallinity tolerance and water resistance. It has been demonstrated that combining starch with gelatin increases the mechanical strength of the created blend coating. Gelatin and customized maize starch were used to create a hybridization edible coating and films that were used to store Red Crimson grapes in the refrigerator. When compared to the uncoated control, the encapsulated grapes had a better appearance after 21 weeks of storage. With the application of chemical nanoparticles to starch, notable enhancement in mechanical, and different barrier properties were observed. However, the tortuous structure created by the highly porous clay caused the application of MMT to starch to limit the absorption of water. Another research work presents a combination nanocomposite based on starch, ZnO, and carboxymethylcellulose, and found that increasing the ZnO-CMC %age from 0 to 5% resulted in significant decrease in water vapour permeability and an improvement in strength properties from 3.9 to 9.8 MPa (by wt.) (Smaoui et al., 2023).

### 2.3 Agar biopolymer

Agar is a flexible carbohydrate derived from Rhodophyceae, a group of marine algae, and seaweeds. It is made up of agarose and agaropectin. Agaropectin is a branching, charged, sulphated, and the non-gelling unit, whereas agarose is an uncharged, regular molecule made up of a-1,4-linked 3,6-anhydro-L-galactose and b-1,3-linked-D-galactose units. Due to its opacity, minimal hydrophilicity, good film-forming capabilities, plentiful availability, and inexpensive cost, agar is a polysaccharide that can be employed for the manufacturing of surface coatings. Nevertheless, agar films' applicability in food packaging was constrained by their poor mechanical characteristics, heat resistance, and antibacterial efficacy. Recent studies have concentrated on enhancing these qualities by fortifying agar coatings with nanofillers including nanoclay and nanocellulose, metallic (Basumatary et al., 2022), and bimetallic nanoparticles. For use in food packaging, agar blends with collagen or carrageenan that also incorporate grapefruit seed extract (GSE) were produced. The claim was made that for rapid aerobic respiration of fresh produce, an antifogging and active ternary nanocomposite film has been developed as antibacterial wrapping (Roy & Rhim, 2023).

### 2.4 Chitosan and chitin

The focus of chitin polymer has been identified as seafood processing waste, including the shells of shrimp, oysters, crabs, krill, crawfish, lobster, and squid. Waste management dumps that are abundant in mushrooms and yeast are also fantastic supplies for chitin and chitosan synthesis. The linearly formed N-acetyl-b-D-glucosamine 1–4 linkage that makes up the heteropolymer chitin gives it an insoluble architecture. This property makes chitin poorly soluble and prevents its direct usage in the production of biopolymers. Therefore, a preparatory N-deacetylation at extreme temperatures and alkaline circumstances is needed for chemical modification. The proportion of acetyl glucosamine converted to glucosamine, or the degree of deacetylation, determines the physicochemical and biological aspects of the chitin. Chitosan is the N-deacetylated derivative of chitin, and it dissolves only moderately in acidic solutions and poorly in water and alkaline solutions. Chitosan has a hard crystalline structure, accessible portable amino groups, and robust hydrogen bonding (Kadhim et al., 2023). A Review in Investigation of Marine Biopolymer (Chitosan) for Bioapplications. *ES Materials & Manufacturing*). Despite changing their physical, chemical, or biological characteristics, chitin and chitosan can undergo chemical modification. Chitosan and chitin can be produced synthetically by acetylation, phosphorylation, Schiff base creation, alkylation, tosylation, silylation, quaternary salt production, sulphation, phthaloylation, and thiolation based on their usage in diverse fields. Additionally, they can be altered through coupling with polymers such as dendrimers, polyurethane, polyethylene glycol, polyether, polyethylene amine, polyethylene amines, polyethylene amines, hyperbranched polymers, PHAs, and PHBs. Related to the structural suppleness of chitosan, it can be readily formed in acidic solutions to create films, fibres, and diverse micromorphologies. Enzymatic (chitosinase and chitinase), chemical (oxidative processes or hydrolysis), or mechanical (heat, irradiation, microwave, food waste valorization for biocomposite synthesis, and ultrasonic) techniques can all be used to break down chitin and chitosan polymers. Chitosan and chitin biopolymers have been extensively researched, along with the production of pullulan utilizing *Aureobasidium mausonii*, polysaccharides created of 2-acetamido-2-deoxy-D-glucuronic acids from *Bacillus licheniformis* SK-1 and N-acetyl-D-glucuronic acid and glucosamine from Aeromonas sp. PTCC1691. Using the biodegradability of two species, Cunninghamella elegans, and Rhizopus arrhizus, green technology was used to make chitin and chitosan from agro-industrial waste (Younes et al., 2015).

### 2.5 Protein

Protein is made up of 20 distinct amino acid subunits combined in various ways. The lengths of these monomers range from 50 to 100,000. The source, pH, temperature, and pressure of the protein, as well as other variables, can all affect its physical, chemical, and biological characteristics. Household waste from both plants and animals can be used to create a range of biodegradable polymers as a renewable resource. Food processing disposal from grains such as sunflower, soybean, and peanut, cereal by-products such as gluten from wheat and zein from maize, and wildlife tissues such as keratin, gelatin and collagen, are almost all processed for enhanced water and thermal resistance, and structural flexibility which can be used as films in preservation, packaging, and thermo-pressed materials such as automobile parts. Biopolymers constructed on gelatin and collagen became frequently used in the biomedical fields as surgical implants as well as temporary replacement implants. The amide connections of the protein polymers can be easily broken by enzyme-like proteases. Given that 50% of the 1.6 108 tonnes of whey produced around the world is lost as animal feed and in wastewater treatment, whey from dairy trash provides an inexhaustible amount of nutrition (Pescuma et al., 2015). Whey is an abundant source of carbs and proteins (lactoferrin, casein, lactose). Whey discharge is an issue for the milk industry, but it is also a cheap source of protein and carbon that is squandered when making biopolymers (Girotto et al., 2015).

### 2.6 Lignin

Three substances that make up lignin, which is an unorganized, highly branched, with a complex framework, and Sinapyl, coniferyl, and p-coumaric alcohols according to Sharmila et al. (2020). Sinapyl, coniferyl, and p-coumaric alcohols are three of the three components that make up lignin, which is an irregularly organized, highly branching, and complicated framework (Sharmila et al., 2020). These three elements serve as the fundamental building blocks of the lignin structure and are collectively referred to as “C9” units since each of them has nine carbon atoms. The lignin’s structural makeup varies depending on the source from which it was extracted. Lignocellulosic materials are those that have lignin around the cellulose matrix. The main sources of lignin components are agricultural and vegetable wastes. Lignin is found in various food products, including tropical fruit peels, wheat straws, corn leaves, peanut husks, and wheat stalks. These enzyme processes oxidize the lignin macromolecule’s aryl ether and phenolic makeup, producing metabolites including vanillic acid and hydrocinnamic acid. PHA biopolymers’ production increased, employing the waste stream of lignocellulosic chemicals by Obruca et al. (2015), it through hydrolysis to create fermentable sugar. Materials that are lignocellulosic are important sources to create various biopolymers since they include lignin and cellulose. There are numerous studies to produce biopolymers from lignocellulosic substances including sugarcane, tequila bagasse, oil empty palm fruit, and such as wheat bran (Sharma et al., 2023).

### 2.7 Oils

Terpenes, triglycerides, and fatty acids generated from biomass have been proven to be effective sources for the creation of biopolymers. Available sources for the manufacture of biopolymers include citrus peels, pulse processing waste, peanut seeds, coconut trash, used cooking oil, and animal fats. The frictional influence of double bonds, length of fatty acids, and level of unsaturation, all have a role in how differently fatty acids and their accompanying biopolymers are structured. The ester component that goes through the processes of transesterification and hydrolysis the reactive compounds located in aliphatic chains at the unsaturated carbone carbon double-bond position, are the two locations where triglycerides can undergo chemical alteration. The hydroxyl groups generated by conversion on these domains make functionalized styrene and acrylics possible. Waste oils, including tallows from both commercial and residential garbage, can be used effectively for biopolymer synthesis as the oils can be incorporated directly as a carbon substrate in the fermentation process without any preparation (Jahani et al., 2023). The cultivation of Cupriavidus necator H16 uses lard waste and palm oil waste from animal sources as a carbon source to produce the maximum yield of PHB, 83%. The same microbe was used by Obruca et al. (2014) to manufacture PHB using used coffee grounds and discarded rapeseed oil, with the highest yields of 67.9% and 89.10%, correspondingly. The nanocomposite formation mechanism is mentioned in Fig. 3.

## 3 Synthesis of different types of biopolymers

### 3.1 Chitin synthesis

Crustacean shells, including those of crab, shrimp, krill, and lobsters, as well as trash produced by the seafood industry worldwide, are the main sources of chitin (Seenuvasan et al., 2014). Crab shells are typically employed out of these key sources for the commercial synthesis of chitin. This is partly because crab shells have a larger chitin level than other shells, such as shrimp shells, which only have a 17% chitin density (Pandharipande and Bhagat., 2016). Ranganathan et al. (2020a, b) supported that trimmings, fins, heads, skin, shells, and viscera are just a few of the processing waste items that come from the global fish industry.

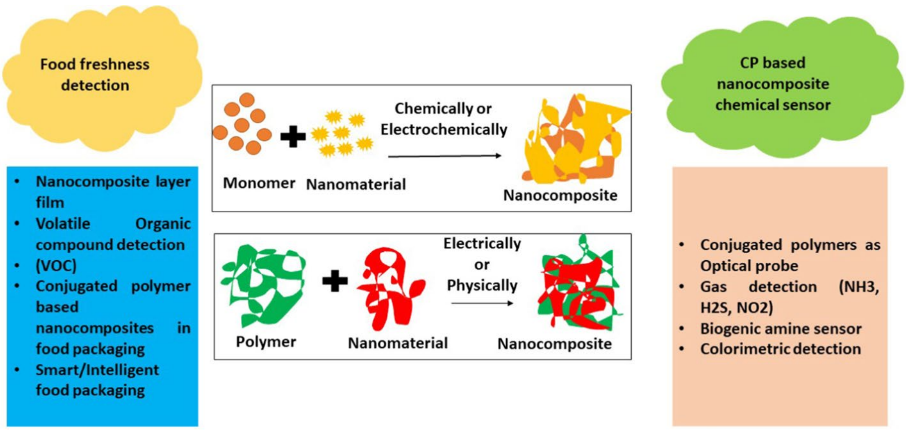


**Fig. 3** Nanocomposite polymer production mechanism

Chitin separation from crustacean exoskeletons requires more time and effort. Chitin and chitosan from crustacean metabolic end have traditionally been extracted using chemical processes. First, deproteinization by alkali treatment is followed by demineralization by acidic treatments at higher temperatures, with further bleaching using chemicals to achieve colourless results. These would be the two fundamental phases in chemical techniques. For these two procedures, NaOH and HCl are favoured the most. The chemical approach of chitin filtration has the advantages of being more efficient in energy use, batch processing, and amount of treatment. (Moussout et al., 2023)

Enzyme-mediated and fermentation separation of chitin are being used in the biological mechanism. Instead of using alkali treatments to deproteinize crustacean exoskeleton, the catalytic technique uses catalysts such as proteolytic enzymes. These proteolytic enzymes are typically derived from gut bacteria in shrimp intestines, *Pseudomonas aeruginosa K-187, Lactobacillus spp., and Bacillus subtiltis*, or by exploiting the proteases contained in the biomasses *(*Ranganathan et al., 2020a, b). Utilizing these wastes not only addresses environmental problems but also makes it possible for them to be recycled into sustainable biological material. Crab shell serves as an ideal primary source among all the accessible shell wastes for the synthesis of chitin because of its composition of 25–30% protein, 40–45% calcium carbonate, and 25–30% chitin (Kaya et al., 2016). Additionally, the disposal of the vast quantities of available crustacean shell debris could harm the ecosystem and wildlife. Additionally, India produces about 1.9 billion tonnes of municipal solid wastes each year, which are a significant source of pollution. These wastes include sugarcane bagasse, coconut shells, wheat straw, jute fibre, and other garbage from mills (Seenuvasan et al., 2021).

## 3.2 Collagen synthesis

Chicken, egg, and fish scraps are used to make collagen. For this extraction, enzymatic and acid hydrolyses are frequently utilized. Non-collagenous protein at cross-linking regions is hydrolysed using NaCl, acetic acid, and pepsin. However, according to ARAÚJO et al. (2018), the main factors affecting collagen output are acetic acid concentration, hydrolysis time, and pepsin content. According to Ranganathan et al. (2020a, b), bone collagen can be decalcified using 0.5 M EDTA while fish epidermis and flippers could be extracted with acetic acid (0.5 M) (ethylenediaminetetraacetic acid). Intriguingly, salt-soluble collagen (1.13%), acid-soluble collagen (14.49%), and pepsin-soluble collagen (49.10%) had the largest yields. Additionally, collagen has been isolated using chicken skin using 0.5 M acetic acid and 1% pepsin. The result still contained fat and non-collagenous protein, but these were eliminated using 20% ethanol and 0.1 N NaOH. In this extraction procedure, type I collagen yield ranged between 10 and 12% (Arunmozhivarman et al., 2017). Yield-based optimization research was done to extract collagen using chicken feet, taking into account factors like pepsin content, acetic acid concentration, and hydrolysis time. With 0.3 mol/L of acetic acid, 0.2% pepsin, and 12 h of hydrolysis, the highest collagen production (72.98%) was discovered (ARAÚJO et al., 2018).

### 3.3 Production of xanthan gum

Xanthan gum is a microbiological exo-polysaccharide formed by Xanthomonas campestris. It is a heteropolysaccharide made up of mannose, glycogen, and glucuronic acid structural characteristics that are repeated penta saccharide units. Xanthan gum is commonly used in the food, beauty, oil storage tanks, and pharmaceutical sector due to its excellent rheological properties, thickening capability, pseudo plasticity, and resistance to heat, acid, and alkali (Niknezhad et al., 2016). Li et al. (2016) established that it is reasonable to implement xanthan gum from kitchen waste alone. In a 5-L fermentor, the xanthan production was 11.73 g/L as well as the reducing sugar transformation and utilization rates were 67.07 and 94.82%, correspondingly. In order to anticipate the experimental outcomes of xanthan gum production in kitchen waste hydrolysate, the logistic and Luedeking–Piret kinetic models are relevant for characterizing the batch fermentation of xanthan gum in a fermentor (Sorze et al., 2023). The xanthan gum synthesized using kitchen waste collective identity with conventional xanthan gum in terms of structure and thermal properties. In moderate KWH, xanthan's pyruvate and acetyl contents improved, as well as further research will be done on how kitchen waste hydrolysate constituents affect the chemical composition of xanthan. Chicken plumage peptone was added to the culture supernatant as an enhancing additive and helped to raise the product's productivity (Ozdal & Kurbanoglu, 2018). With only a small amount of urea and potassium supplementation, X. campestris has also been explored for the manufacture of xanthan gum from coconut shells and cocoa husks (da Silva et al., 2018). Starch is a common waste product in a facility that makes potato chips, primarily because of the cutting and rinsing operations. Enzymatic hydrolysis was used to produce biopolymers from the processing of potatoes. The maximum glucose concentration is produced by turning roughly 96% of the potato starch trash into malt in a 90:10 proportion. Potato debris has indeed been employed as an alternative substrate for the bacterium bacillus X. campestris to produce xanthan gum in solid, immersed, and quasi-states. According to research, immersed state fermentation produces less xanthan than liquid and semi-fermentation (Ranganathan et al., 2020a, b).

### 3.4 Polyhydroxyalkanoates (PHAs) synthesis

As per the study of Samorì et al. (2022), it is concluded that polyhydroxyalkanoates (PHAs) are microbially polyesters made by a range of species that can store carbon and PHA pellets as energy inside their cells. PHAs can address the demand for biobased polymers made from renewable resources because they degrade both aerobically and anaerobically. In addition, PHAs could be used in typical applications where degradation is not necessary, such as functional goods that are anticipated to disintegrate (such as capsules holding seeds or herbicides) (e.g. bags, packaging). Determining the chemical structure of the monomer beforehand is necessary to target particular qualities of the substance for a variety of applications since the length of the monomer unit is crucial to the properties of the final polymerization. PHAs with short chains (scl-PHAs) include three to five carbon atoms. 4-hydroxybutyrate (4HB), 3-hydroxybutyrate (3HB), or 3-hydroxyvalerate are a few instances of the monomeric units for scl-PHAs (3HV). The thermoplastic characteristics of the scl-PHA composites are comparable to those of polypropylene (Puppi et al., 2019). *Hydrogenophaga sp., Bacillus sp., Cupriavidus sp., Comamonas p., Pseudomonas sp., Burkholderia sp., Haloferax sp., Acinetobacter sp., and Azohydromonas sp.* are the most often employed microbiological variants for the synthesis of PHB food waste must adequately planning in order to be converted into PHA. To degrade the accumulating evidence indicates, this procedure either uses chemical or biological processing. After that, PHA-producing microbes use the accessible carbon supply to make PHA (Rodriguez-Perez et al., 2018; Nielsen et al., 2017). It is essential to remember that the garbage feedstock used to make PHA have varying amounts of nitrogen and phosphorus. An adequate combination of nitrogen, carbon, and phosphorus is required for the formation of PHA; an overabundance of any of these elements may hinder the process. PHA's structural characteristics, such as brittleness and hardness, are determined by its subunit composition, which changes according to the bacteria utilized and the substrate (Johnston et al., 2018; Zhou et al., 2023).

### 3.5 Fabrication of lignin and hemicelluloses

Sugarcane bagasse, an inexpensive by-product of the sugar industry, is the dominant contributor of lignocelluloses. Ash, lignin, cellulose, and lignocellulose are the primary components (Peng et al., 2022). In comparison with cellulose and hemicellulose, lignin, a precursor of lignocellulose, seems to be more resilient to most environmental stressors. According to reports, aqueous solution and ethanol solution are used to isolate lignin. In comparison with 40% NaOH in 50% ethanol, the extraction of lignin has been observed to be greater using 40% NaOH in filtered water (20.4%) (Jonglertjunya et al., 2014). The existence of fibrous residues in sugarcane bagasse slows and complicates the microbiological breakdown process. Bagasse has undergone pre-treatment to increase feedstock accessibility and fermentation in an effort to get around this complication. By using alkali, hemicelluloses are recovered from bagasse and cereal straw. Higher amounts of alkali cause the lignin and hemicelluloses in bagasse to lose their ether bond (Ranganathan et al., 2020a, b). Bagasse was alkaline-treated with 1 and 3% NaOH, and the yield of hemicelluloses was 25.1%. Gradually precipitating with ethanol has efficiently sub-fractioned the hemicellulosic fraction obtained through successive extraction (Ranganathan et al., 2020a, b). Alkali treatment has been shown to be a successful technique for fractional distillation lignin and hemicelluloses that are alkali-soluble from biomasses and straw. Hemicelluloses are also lignified and then solubilized using hydrogen peroxide (H2O2) (Ranganathan et al., 2020a, b). Trilokesh and Uppuluri (2019) demonstrated that the quasi-jackfruit peel was efficiently used to separate SCNCs and cellulose using sulphuric acid degradation and sodium chlorite treatment. Twenty per cent by weight of both the separated homocellulose and 44% by weight (on a dry weight basis), was cellulose. By using SEM, NMR, FTIR, XRD, DSC, and TGA, the separated cellulose was examined for its morphological, functional, crystal, and thermal characteristics. By using TEM, zeta size, zeta potential, and HPLC, the SCNCs were evaluated for their size, charge density, and monomers characterization. The isolated SCNCs and cellulose had similar traits to those described in the literature and were discovered to be free of lignin and hemicellulose (Xie et al., 2023).

# 4 Potential applications and limitations of biopolymers based on food wastes

## 4.1 Food industry

Proteins and polysaccharides are the two subcategories of food biopolymers. In both plant and animal tissues, proteins are amino acid polymers. Proteins in food are less structurally stable under shear, heat, and pH (Mellinas et al., 2020). Due to their potential to interact with other food constituents to enhance the physicochemical characteristics and durability, biopolymers are currently a common component of specialized structures with qualities utilized in the processing of food (Varjani et al., 2023). During the storage and preparation of food at various pressure and temperatures, food constituents go through phase transitions (liquid-gel or liquid-solid) (Taherimehr et al., 2021). The stability and quality of food are impacted by these modifications. This is due to the relationship between changes in the physical features of foods and phase transitions in their constituent parts. Biopolymers have numerous properties that can be used in numerous applications (Table 2).

## 4.2 Pharma industry

The development of science and technology has significantly increased life expectancy. This has led to a decrease in mortality and morbidity rates thanks to a variety of inventive strategies and new technology. The use of drug delivery strategies to boost the effectiveness of bioactive molecules is a crucial strategy for treating illnesses, and there has been a lot of advancement in this field (Peng et al., 2022). Natural polymers are frequently used in regenerative medicine, despite being cleansed to avoid a foreign body reaction after implantation. Because they may be removed without surgery once the medication has been released and because they degrade in the body, biodegradable polymers were chosen for the drug delivery method (Chadha et al., 2022). Biopolymers are widely used in a variety of well-known biomedical applications, such as soft-tissue replacement vascular grafts, plasmapheresis units, contact lenses, adhesives, sutures, blood substitutes, dialyzers, liver, pancreas, bladder, catheters, kidney, bone cement, internal and external ear repairs, coatings for pharmaceutical capsules and tablets, and cardiac assist devices (Sahajpal et al., 2022; Swetha et al., 2023). Different medical applications of biopolymers are mentioned in Table 3.

## 4.3 Water treatment

The survival of all living species faces significant difficulties due to the global shortage of clean water. The removal of harmful and hazardous wastes from water requires the use of advanced treatment procedures for water and waste, such as filter separation and ion exchange separation. In order to overcome this crucial issue, membrane technology is

**Table 2** Application and properties of different biopolymers

| Biopolymers | Properties | Applications | References |
|---|---|---|---|
| Guar gum | Improving texture<br>Thickening agent | Pie fillings<br>Syrups<br>Jams | Baranwal et al. (2022) |
| Chitosan and Chitin | Biodegradability<br>Nontoxicity<br>Chelating<br>Antioxidant<br>Anticoagulant<br>Antimicrobial<br>Biocompatible | Protective coating<br>Water resistant<br>Confectionary products | Soukoulis et al. (2018) |
| Starch | Stabilizer | Salad dressing<br>Ice cream<br>Coating | Liu et al. (2021) |
| Pectins | Adhesive | Jam<br>Jellies<br>Marmalades<br>Glazing and icing | Taherimehr et al. (2021) |
| Gellan | Inhibitor | Sugar syrups<br>Frozen foods | Baranwal et al. (2022) |
| Agar | Swelling agent | Meat products | Mellinas et al. (2020) |
| Alginate | Gelling agent<br>Thickening agent | Milk based confectionary<br>Jellies | Liu et al. (2021) |
| Carboxymethyl cellulose | Coating<br>Emulsifying agent | Salad dressing<br>Confectionary | Baranwal et al. (2022) |
| Hemicellulose | Binder | Pet foods | Mellines et al. (2020) |
| Xanthan gum | Foam stabilizer | Beer<br>Carbonated beverages | Baranwal et al. (2022) |
| Pullulan | Film formation<br>Thickening agent | Coating for protection | Baranwal et al. (2022) |

crucial. Nanocomposite membranes (NCMs) are the most popular in membrane technology due to their ease. These membranes and the components that make them up are inexpensive, energy-efficient, and environmentally benign. Additionally, they are practical and flexible in terms of functioning (Ince et al., 2022). Despite several drawbacks including relatively high energy consumption, permeability, limited lifetime, and low fouling resistance, polymers are frequently used materials in water/wastewater treatment. The creation of low-energy, affordable, and useful membranes is essential for the removal of pollutants from water and waste. In particular, the incorporation of nanosized elements into the polymer matrix has significantly advanced efforts to address the problems associated with water treatment for newly created and produced polymeric membranes (Barman et al., 2021).

According to Pandey (2020), different types of reactions, including esterification, xanthation, oxidation, acylation, etherification, Schiff base reaction, phosphonium enhancement, and alkylation, can be used to modify chemicals. Numerous studies have demonstrated chitosan's remarkable flocculation and coagulation strengths for dye molecules in textile wastewater, toxic metals and polyphenol molecules in cardboard-mill wastewater, organic matter in pulp and paper mill wastewater, and inorganic disciplinary actions in kaolinite suspension (Li et al., 2013b). The wide range of applications shows the endless

**Table 3** Different pharmaceutical applications of Biopolymers

| Biopolymer | Medical application | References |
|---|---|---|
| Collagen | Surface coating for tissue culture plates<br>Simple gels for the structure of cells | Peng et al. (2022) |
| Starch | Regeneration of bone and cartilages<br>Useful in spinal cord injury treatment | Jaya et al. (2022) |
| Keratin | Regeneration of skin | Sahajpal et al. (2022) |
| Alginate | Tissue engineering<br>Regenerative medicines | Baranwal et al. (2022) |
| Hyaluronic acid | Lubrication and treatment of damages joints | Mahmood et al. (2022) |
| Fibrin | Blood clotting<br>Wound healing<br>Tumour growth | Peng et al. (2022) |
| Agarose | Regeneration of skeletal tissue | Jaya et al. (2022) |
| Elastin | Cell encapsulation<br>Orthopaedics | Baranwal et al. (2022) |
| Carrageenan | Wound healing<br>Cell delivery system | Sahajpal et al. (2022) |

possibilities of chitosan and chitosan compounds for water and wastewater treatment. Blended compound nanocomposite exhibits appealing properties such as high conductivity and potent antimicrobial activity. ZnO and ZnS are low-toxic materials, making them promising candidates for a variety of optoelectronic and biomedical applications. The ZnS–ZnO nanocomposite has a high surface-to-volume ratio and effective antimicrobial activity. Semiconductors made of ZnS and ZnO have a direct and wide band gap with a mixed phase. Both shapes have different structures and bandgap energies, which gives them exciting properties. The photoluminescence (PL) properties of the ZnS–ZnO nanocomposite show a red shift and lesser wavelength optical absorption. Aqueous foams are used as a template for the synthesis of nanoparticles as well. The process includes creating a highly stable liquid foam by electrostatically complexing silver ions with an anionic surfactant aerosol. The froth is then decreased by adding sodium borohydride and drained off. Given how durable these silver nanoparticles are in solutions, it seems likely that the aerosol stabilizes them. This technique produced nanoparticles with a diameter of 5 to 40 nm (Prabhu et al., 2012). With its antibacterial properties, nanosilver can prevent the growth of a variety of "friendly" microorganisms in the soil. Silver can stop the denitrification method, which entails turning nitrates into nitrogen gas that is necessary for the plants, by having harmful effects on the denitrifying bacteria. Eutrophication of rivers, lakes, and marine habitats caused by a loss of environmental denitrification can result in ecosystem collapse (Barman et al., 2021).

### 4.4 Cosmetic product manufacturing

Baby products, intimate care products, and cosmetics meant for use near the eyes all typically have various restrictions on the preservatives they can contain. Because the amount, length, frequency, and route of exposure can significantly affect a compound's toxicity, some preservatives are restricted. Even though preservatives are included in cosmetic formulas to protect the consumer's safety, most of them on the market today exhibit certain

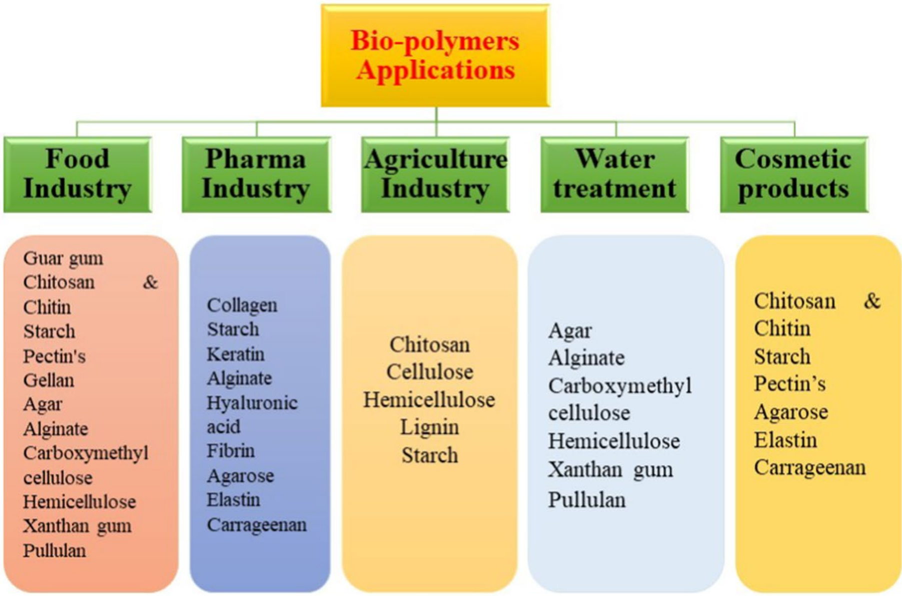


**Fig. 4** List of biopolymers utilized in various industries

tolerance reactions when used (Angelopoulou et al., 2022). Primary packaging is crucial for the preservation and safety of cosmetic and food products because it shields them from microbial contamination and subsequent spoilage. However, it may also interact with the product by allowing substances it may contain to migrate (including antimicrobials) or by allowing atmospheric agents like oxygen to travel through the product (Liu et al., 2021). This is the rationale for why the cosmetic file needs to include details on the primary container's composition, potential impurities, and potential migration. Additionally, it is required to conduct compatibility testing with the cosmetic product and composition. Chitosan and its derivatives are commonly used in cosmetics because of their antimicrobial, defensive, humectant, and antioxidant properties (Mahmood et al., 2022). Application of biopolymers is classified in Fig. 4.

## 5 Difficulties and limitations of the study

The necessity for more studies and developments in several areas prevents the major use of food leftovers for the creation of nanocomposite polymers in sustainable development (Maraveas., 2020). These include the discovery of new materials, the creation of nanocomposite materials, performance testing, life cycle analysis, cost-effectiveness and scalability, application development, and technological improvements. We can get through the current obstacles and fully realise the benefits of food waste and nanocomposite polymers for sustainable development by concentrating on these variables. This would result in less waste, better resource management, and the creation of eco-friendly materials, all of which would help ensure a more sustainable future (Tajik et al., 2021). The significant use of food wastes in the creation of nanocomposite polymers in sustainable development offers a viable way to address environmental and food waste disposal issues. However, in order to fully realise the potential of this novel strategy, a number of significant research gaps must be filled. The requirement for standardized and improved synthesis procedures for producing nanocomposite polymers derived from food waste is one of the main research gaps. Diverse approaches are being investigated, but the general adoption of these materials is hampered by a lack of consistency and standardization. To guarantee the consistent quality and performance of the biocomposites, it is essential to establish clear and repeatable processes. A crucial stage in the creation of nanocomposites is the incorporation of organic and inorganic nanoparticles into biopolymers. However, a thorough knowledge of the interactions between these nanoparticles and biopolymers is lacking. To better understand the underlying principles and to create more specialized and efficient nanocomposites, more study is needed. Biocomposites made from food waste have demonstrated promise in terms of mechanical strength and barrier qualities, but further research is needed to determine their long-term stability and resistance to a variety of environmental factors. Studies should concentrate on determining how these materials degrade, if nanoparticles might leach, and how exposure to various environments affects how well they function. Any new material has a huge hurdle when it transitions from production at the laboratory size to industrial scale. Researchers must look into scalable production methods that can satisfy commercial expectations without sacrificing the characteristics of the nanocomposite polymers. While food waste-derived biocomposites are more sustainable than conventional synthetic polymers, a comprehensive life cycle assessment is needed to understand their overall environmental impact. To identify potential environmental hotspots and further improve their sustainability, this study should take into account the whole life cycle, from raw material extraction to disposal. It is essential to carefully assess the health and safety consequences of these biocomposites given their expanding use in a variety of industries. Assessing potential concerns related to nanoparticle exposure and looking into ways to lessen any negative effects on both human health and the environment are part of this process.

## 6 Conclusion and future perspective

Biowaste should be rebuilt using the concepts of the circular economy because it is manufactured on an astonishing scale every year—billions of kilogrammes. Considering this, it is ideal to execute sustainable growth through a closed loop for recycling and transformation, without endangering or depleting the natural resources. Food wastes can be fundamentally changed into a variety of end-use goods and materials using physical, chemical, or biological processes. Various food wastes which can be derived into biopolymers and nanocomposites are the focus of this review. These sources include a variety of widely accessible materials like collagen, chitin, chitosan, hydroxyapatites, cellulose, lignin, and other C-based feedstocks for metal, metal oxide nanoparticles, biopolymeric, and nanocarbon structures. Implementations for these components include environmental remediation, water treatment, the pharma industry, the agriculture industry, and the cosmetic industry. However, many of these studies are still in the early stages and need to be thoroughly examined from both a technical and socio-ecological perspective. These factors include energy balance and costs, environmental emissions, toxicity, and biodegradability problems. In terms of sustainable development, nanocomposite polymers are a notable finding since they can cut down on food waste and encourage environmental protection. Among the most important concerns facing contemporary civilization is food waste, and nanocomposite polymers provide a possible answer. Food waste may be used as a raw material to create nanocomposite polymers, which will help us stop resource depletion and environmental damage. Food wastes have a bright future if they can be converted into useful materials for use in packaging, cosmetics, pharmaceutical, and wastewater treatment, among other sectors of industry. When compared to conventional plastic substances, nanocomposite polymers derived from food scraps have better physical and thermal resistance while also being biodegradable. Since these components may be utilized to develop food packaging materials with longer shelf life, utilizing nanocomposite polymers in the presence of food wastes holds great promise for the foreseeable future. They can also contribute to extending the shelf life of perishable items by providing better storage conditions. By preventing moisture, gases, and other pollutants from entering food packaging, nanocomposite polymers ensure the food's safety and freshness for a prolonged length of time. Nanocomposite polymers are ideal for use in building materials like flooring tiles and insulation panels created from recovered food waste like eggshells because they have exceptional mechanical strength and durability. The potential benefits of employing nanocomposite polymers to recycle food wastes in the future are encouraging and may result in more sustainable practices and lifestyles in many facets of society. It is reasonable to conclude that product packaging made of nanocomposite polymers supports global environmental initiatives while also offering an effective way to prevent food waste. They have a great deal of promise for developing more environmentally friendly goods that do not overuse resources that are renewable or negatively impact the environment. Utilizing food waste-derived nanocomposite polymers is an inventive strategy for sustainability that has the potential to revolutionize several sectors and advance green living around the globe.

The potential of employing food waste as a feedstock to produce bioplastics should be further investigated. Exploring various food trash sources, notably fruit peels, vegetable trimmings, and agricultural waste, and optimizing their conversion into polymer intermediates can help with this. Studies can be performed for the development of nanocomposite plastics by adding food waste-derived nanofillers to polymer matrices. To do this, it may be necessary to examine different food waste-based nanofillers, such as cellulose nanocrystals, chitosan nanoparticles, or starch nanoparticles, and evaluate the way they work with various polymer matrices. Nanocomposite polymers should be evaluated for their mechanical, thermal, and barrier properties to make sure they meet the minimum performance standards for diverse applications. This may entail doing thorough description tests, such as measures of gas permeability, heat resistance, elongation at break, and tensile strength. Determining the environmental impact of the nanocomposite polymers produced from food waste, perform a full life cycle assessment (LCA). Examine sustainable they are compared to traditional polymer materials and note any areas that might be made more efficient about of power use, greenhouse gas emissions, and waste production. The viability and sustainability of using food particles to make nanocomposite polymers from an economic standpoint. Analyse the costs associated with the procurement, interpreting, and assembly of feedstocks and suggest potential improvements to the manufacturing process for large-scale production. All possible uses for nanocomposite polymers made from food debris in a range of sectors, including packaging, automotive, construction, and textiles can be examined. To enhance the production of nanocomposite polymers from food waste, keep up with the most recent developments in processing technologies, such as melt extrusion, injection moulding, or 3D printing. The special properties of biopolymers, including biocompatibility and the ability to degrade, have significant advantages and improve the likelihood of their use in implantable medical uses. These novel materials are critical in medicine because synthetic materials do not satisfy the requirements of biological systems. These polymers have several advantages compared to traditional petroleum-based polymers. They possess superior mechanical properties and are also biodegradable, making them more eco-friendly. Additionally, biocomposite polymers can be produced more cheaply than traditional polymers. In terms of food waste, biocomposite polymers can be created by combining food waste with other polymers. This can be done by either melting the food waste and combining it with other polymers or by chemically binding the food waste to other polymers. The resulting biocomposite polymer can then be used for a variety of applications, from packaging to fabric. By utilizing food waste in the production of biocomposite polymers, we can reduce the amount of food waste going to landfills, while also creating a more sustainable and eco-friendly material. This strategy has several benefits, including the reduction of waste, conservation of resources, and creation of eco-friendly products for a better tomorrow.

**Funding** No funding was received to assist with the preparation of this manuscript.

**Data availability** There are no research data to present for this project.

## Declarations

**Conflict of interest** There is no conflict of interest between the authors.

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