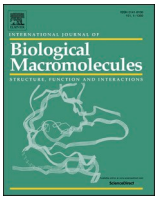
International Journal of Biological Macromolecules 242 (2023) 124803

Contents lists available at ScienceDirect

International Journal of Biological Macromolecules

journal homepage: www.elsevier.com/locate/ijbiomac



Essential characteristics improvement of metallic nanoparticles loaded carbohydrate polymeric films - A review

Yezihalem Zena [a], Selvakumar Periyasamy [a,*], Melaku Tesfaye [a], Zelalem Tumsa [a], Mani Jayakumar [b], Badr A. Mohamed [c], Perumal Asaithambi [d], Tejraj M. Aminabhavi [e,*]

[a] Department of Chemical Engineering, School of Mechanical, Chemical and Materials Engineering, Adama Science and Technology University, Adama 1888, Ethiopia
[b] Department of Chemical Engineering, Haramaya Institute of Technology, Haramaya University, P.O. Box No. 138, Haramaya, Dire Dawa, Ethiopia
[c] Department of Agricultural Engineering, Cairo University, Giza 12613, Egypt
[d] Department of Water Supply and Environmental Engineering, Faculty of Civil and Environmental Engineering, Jimma Institute of Technology, Jimma University, Po Box – 378, Jimma, Ethiopia
[e] Center for Energy and Environment, School of Advanced Sciences, KLE Technological University, Hubballi 580 031, India

ARTICLE INFO

Keywords:
Carbohydrates
Biopolymers
Metallic nanoparticles
Biofilm preparation
Biofilm properties

ABSTRACT

Petroleum-based films have contributed immensely to various environmental issues. Developing green-based films from carbohydrate polymers is crucial for addressing the harms encountered. However, some limitations exist on their property, processibility, and applicability that prohibit their processing for further developments. This review discusses the potential carbohydrate polymers and their sources, film preparation methods, such as solvent-casting, tape-casting, extrusion, and thermo-mechanical compressions for green-based films using various biological polymers with their merits and demerits. Research outcomes revealed that the essential characteristics improvement achieved by incorporating different metallic nanoparticles has significantly reformed the properties of biofilms, including crystallization, mechanical stability, thermal stability, barrier function, and antimicrobial activity. The property-enhanced bio-based films made with nanoparticles are potentially interested in replacing fossil-based films in various areas, including food-packaging applications. The review paves a new way for the commercial use of numerous carbohydrate polymers to help maintain a sustainable green environment.

1. Introduction

Petroleum-based polymers have been widely used in day-to-day human activities for many years [1–4]. Most synthetic polymers produced from petrochemical products are not degradable, but they can be recycled after their applications and have limitations when used as packaging materials [5–8]. Environmentally benign biopolymers have been extensively studied in recent years as promising candidates for maintaining a sustainable green environment without compromising the essential properties required for their end-use applications [9–12]. Biofilms derived from carbohydrate polymers can be bioplastics developed from biomass such as cellulose, starch, chitosan and poly(lactic acid) are the most promising materials to replace conventional petroleum-based films and for other applications [13–21]. The essential properties of carbohydrate polymers are to be considered as promising substituting agents for conventional polymers due to their abundance, biodegradability, biocompatibility, and unique features compared to synthetic polymers [22–25].

The biofilms fabricated from carbohydrate polymers have their limitations in processing and end-use applications due to their slow crystallization, poor mechanical strength, low thermal stability, low gas and water barrier properties [26–30]. Recently many attempts have been made to overcome these drawbacks to enhance the processability of biofilms through physical and chemical modifications. Chemical

Abbreviations: CMC, carboxymethyl cellulose; DDA, degree of deacetylation; DSC, differential scanning calorimeter; E, Young's modulus; EB, elongation at break; OP, oxygen permeability; PBAT, polybutylene adipate terephthalate; PLA, poly(lactic acid); SPI, soy protein isolate; Tc, crystallization temperature; T_{dmax}, maximum decomposition temperature; Tg, glass transition temperature; TGA, thermogravimetric analyzer; Tm, melting temperature; T_{onset}, onset degradation temperature; TS, tensile strength; WVP, water vapor permeability; Xc, degree of crystallinity.

* Corresponding authors.
E-mail addresses: selvaa26kumar@gmail.com (S. Periyasamy), aminabhavit@gmail.com (T.M. Aminabhavi).

https://doi.org/10.1016/j.ijbiomac.2023.124803
Received 18 December 2022; Received in revised form 24 April 2023; Accepted 6 May 2023
Available online 12 May 2023

modifications such as grafting, crosslinking, and branching are the commonly used techniques to modify the properties of naturally occurring carbohydrate polymers such as cellulose, starch, and chitosan. Most of these have film-forming abilities. Introducing metal nanoparticles into these biofilms has enhanced their properties further [30–33]. Innumerable techniques have been developed to incorporate metal nanoparticles into these biopolymers, such as tape casting [34–36], solvent casting [37–39], extrusion [40–42], and thermo-mechanical compression [43–45]. Considering the distinctive features of nanoparticles and biopolymers to produce biofilms may be the best way to enhance the limited properties of the biopolymers. To date, a very limited comprehensive review has been published on various property changes of biopolymers with the incorporation of metal nanoparticles. Hence, this review discusses important carbohydrate polymers, their primary sources, recovery methods, and functional modification techniques for film-forming ability. In addition, nanoparticles incorporate techniques, changes in biofilm properties, difficulties in film-forming processes, and future opportunities are discussed in detail.

2. Carbohydrate polymers in biofilms preparation

Naturally existing carbohydrate polymers are good materials in film-preparing processes to seek different applications. Among the many wide-ranging materials, cellulose, starch, chitosan, and carbohydrate-derived polymer, i.e., poly (lactic acid), possess good film-forming properties. Herein, individual natural polymers and their modifications for the preparation of biofilms are covered.

2.1. Cellulose and its modification

Cellulose is a hydrophobic biopolymer formed from thousands of repeating D-glucose units bonded through the unique β-1,4 glycosidic bonds [46,47]. It is found in nature abundantly and is one of the major components of lignocellulose [48]. The major natural sources of cellulose are plants [49], animals [50], bacteria [51], and algae [52]. Cellulose can also be recovered from different sources to offer film-forming properties. Cellulose can be recovered (68.2 %) from water hyacinth (*Eichhornia crassipe*) using the subcritical water pretreatment method [53], and using sequential two-step treatment, 28.3 % recovery of cellulose fibers can be obtained [54]. Green tea can be used as a substrate for the fermentation of *Acetobacter xylinum* bacteria to produce bacterial cellulose nanofibrils with a diameter of 40 nm [55] and 19.7 % of α-cellulose can be recovered from the marine green algae biomass residue of *Dunaliella tertiolecta* [56].

Cellulose and its derivatives have been widely explored to form films for several applications due to their unique physical and chemical properties, of which bio-degradability and bio-compatibility [57], high viscosity [58], nano-fibrillar three-dimensional network structure [59], optical transparency [60] and tunable porous structure [61] are quite attractive for film preparation. In addition, their insolubility in water and other organic solvents, bio-degradable, chirality characteristics, more crystalline nature than starch, and being an odorless polymer with a density of 1.5 g/cm^3 [62] are their necessary characteristics. Since cellulose cannot be processed directly as a film-forming material, so attempts have been made to modify its structure by grafting it with other polymers [63]. Other techniques, such as free radical polymerization, ring-opening polymerization, atom transfer radical polymerization, reversible addition-fragmentation chain transfer polymerization, and nitrogen oxide-mediated polymerization, have been widely explored. Cellulose films and cellulose nano-fibers have been cross-linked with glutaraldehyde by tempo oxidation. The modification of cellulose via crosslinking using epichlorohydrin produced a cellulose-based biofilm.

2.2. Starch and its modification

Starch is a linear and a branched biopolymer present as semi-crystalline granules formed through the photosynthesis of plants [64–68], which comprises two major polysaccharides, namely amylose and amylopectin [69]. Films with extra amounts of amylose normally possess higher film-forming properties, mechanical strength elongation, and gas barrier properties [14]. Recently, 40 % of purple yam starch was recovered using ultrasound-assisted extraction from purple yam starch [70]. Starch recovery from turmeric wastes on a dry basis yielded 3.33 % using pressurized liquid extraction and supercritical technology [71]. The amount of starch recovered on a dry basis from three discarded potato varieties, namely Agria, Kennebec, and Neiker was recorded up to 91.2 %, 83.4 %, and 88.6 %, respectively [72]. Starch-rich seed, namely quinoa (*Chenopodium quinoa*), was processed by wet-milling with an absolute starch recovery in the range of 81.9 to 87.2 % [73].

In recent years, starch has been getting much attention as a film-forming biopolymer due to its biodegradability and low cost [74], abundancy [75], non-toxicity, and ease of process as edible films [76], and it has thermoplasticity as a packaging material [77]. Like any other biopolymer, starch has many common properties with other biopolymers, among which its unique properties are poor barrier properties [78], low mechanical strength, and moisture sensitivity [76], which are some of the drawbacks associated with starch. Also, it is bio-degradable [79], insoluble in cold water and tends to retrograde [80]. Different techniques have been employed to modify starch into a film-forming biopolymer. Qiao et al. [81] reported that surface modification, i.e., grafting of starch films by different alkahnols would increase its carbon to oxygen mass ratio and mobility of the plasticizers. To use starch for different applications, grafting can be done using nitroxide-mediated polymerization [82]. *Triphala churna* has modified starch nanoparticles via graft copolymerization to make it a promising drug delivery polymer [83]. Native starch, i.e., sago, was passed through oxidation, acetylation, and different chemical modifications, which resulted in acetalyed starch showing a superior property in biofilm preparations [84].

To alter the property of carbohydrate polymers, another polymeric macromolecule, i.e., protein, is also combined to prepare biofilms. Protein is a complex biomolecule composed of amino acids linked together to each other, which interacts with many types of carbohydrate molecules [85]. Proteins' technological-functional properties are responsible for the look, texture, and stability of food items [86]. The sources of proteins are natural, which include animals, whey protein from diaries [87] and plants such as soy protein from soya beans [88], and red lentils (*Lens culinaris*) proteins [89]. Proteins, like other biopolymers, can be recovered from different protein-rich wastes using different protein-recovering techniques [90,91]. Different extractants, namely deionized water, NaOH, and Na-pyrophosphate, were used to recover soluble proteins from three soil types: Cambisol, Ferralsol, and Histosol. The maximum recovery achieved was 61–80 % and 45–75 % using NaOH and Na-pyrophosphate, respectively [92,93]. It is biodegradable and have good mechanical strength, excellent oxygen barrier properties [87], oil-resisting capacity [94], have the capacity to produce gels, emulsions, and foams, as well as a valuable nutritional index [95] having a high molecular weight and good heat stability [96]. The proteins are stable at different pH, temperatures, and salt levels and have poor water vapor resistance [97], solubility, hydration, and swelling power [98–101].

2.3. Chitosan and its modification

Chitosan is a naturally abundant polycationic polysaccharide next to cellulose composed of poly-β-1,4-linked glucosamine and N-acetyl-d-glucosamine [102]. Chitosan is usually obtained by deacetylation of chitin [103]. It is only soluble in acidic solutions due to the protonation of the NH_2 groups on the C_2 position of the D-glucosamine repeat units

[104]. The natural monomer source of chitosan is chitin which is derived from biological sources like crustaceans [105], insects [106], the cuticle of some arthropods [107], and the cell wall of fungi [105]. There are several other methods to recover and extract chitosan from biological sources.

Using Graviolaextracts as an extractor, chitosan with a high degree of deacetylation, about 94.86 % on the 3rd day, was recovered from commercially available chitin and seafood waste [108]. The chitin from Shrimp shells (*Litopenaeus vannamei*) was treated with 12.5 M NaOH at 65 °C for 12 h to recover chitosan with 56.10–88.76 % degree of deacetylation [109]. On the other hand, chitosan from Shrimp shell waste using a common chemical method was recovered with a degree of deacetylation of 88.89 % [110]. Doğdu et al. (2021) [111] isolated the chitosan from the exoskeleton of the invasive swimming crab *Charybdis longicollis* using chemical methods and the yield of chitosan produced from extracted chitin was 80.23 %. Using chemical techniques, recovery of chitin and chitosan from *Callinectes amnicola* (crab) and *Penaeus notialis* (shrimp) shell wastes was performed. A higher chitin yield of 26.08 %, a higher chitosan yield of 16.93 %, and a higher degree of deacetylation (DDA) of 89.73 % were obtained from the shrimp shell whereas crab shell yielded chitin of 19.36 %, chitosan of 13.29 % and the DDA of 84.20 % [112].

The physicochemical properties that attract the research society to select and process chitosan as a film-forming biopolymer are its molecular weight and DDA [113], antioxidant and antifungal activity [114–116], suitable carrier property for other materials [117], non-toxic, biodegradability and biocompatibility [118]. The specific physicò-chemical properties associated with chitosan are it is insoluble in water and common organic solvents, but it is soluble in weak acids, has poor mechanical properties [119,120], has a poor water resistance [40], an excellent oxygen barrier [121], large scale availability [122] and presence of practical groups for chemical adjustments [123].

A unique feature of chitosan that attracts many researchers can potentially be used when it is functionally modified. The most common modification techniques to this particular biopolymer are crosslinking and grafting. The grafting of chitosan film with corrole macrocycle resulted in property enhancement of the chitosan film. Using the carbodiimide-mediated grafting method, chitosan was functionalized by three different hydroxycinnamic acids to bring up the chitosan film into packaging material [124]. Liu et al. (2021) [125] conducted the same grafting method as the previous one, and five different hydroxybenzoic acids were grafted on chitosan with different grafting ratios. Three different dialdehyde derivatives were used to be cross-linked with chitosan to bring up the chitosan films into biomedical applications [126]. Khouri et al. (2019) [127] conducted heterogeneous cross-linking of chitosan with citric acid by varying concentrations of a model cross-linker to obtain its effect on the viscoelastic properties of the chitosan films.

2.4. Poly (lactic acid)

Poly(lactic acid) is bio-based, bio-degradable, and bio-compatible linear aliphatic thermoplastic biopolymer that can be produced by the most well-known production method, which is ring-opening polymerization which results in the production of optical isomers of poly(lactic acid) [63,128–130]. This polymer source is usually lactic acid found in nature, particularly in sugar cane, corn starch, and other bio-mass products [131,132]. Poly(lactic acid) possesses attractive physico-chemical properties to be utilized as a biofilm-making biopolymer and these are its high elastic modulus and high transparency [133] and good mechanical property, i.e., tensile strength [125]. It is non-toxic and bio-compatible for foods [131], good thermal processibility [134]. The properties of poly (lactic acid) include low thermal stability [135], low crystallinity [136], and high brittleness and bio-compatibility [137,138].

In addition to Poly(lactic acid), (butylene-adipate-*co*-terephthalate) is a flexible synthetic aliphatic-aromatic co-polymer with outstanding hydrophilic and processing qualities used for biofilm preparation [139]. It consists of two types of comonomers, a rigid butylene terephthalate, composed of 1, 4 butanediol and terephthalic acid monomers. In contrast, the flexible butylene adipate portion is made up of 1,4 butanediol and adipic acid monomers [140]. It is derived from common petrochemicals—purified terephthalic acid, butanediol, and adipic acid, yet biodegradable [141]. Different polymers and their common sources are presented in Table 1. The properties exhibited by this particular polymer play a vital role in utilizing it as a potential film-making and blending polymer and those properties are biodegradability(from aliphatic moiety) [142], good mechanical property (from the aromatic part of PBAT) [143], good crystallization and thermal stability [16], high ductility [144], high elongation at break [145], good processability, high flexibility and toughness [140] has low density [146], good permeability to gas and vapors [147] and good moisture resistance, stretching and impact [148,149]. It is a polymer that possesses different unique physical properties. Among them, the high melt viscosity and crystallization rate [150], low elastic modulus [151], and insoluble in water [152] are the major properties that are usually considered in processing it for different applications. Various biopolymers and their unique features are listed in Table 2.

3. Biofilms preparation methods

Biopolymers can be described as natural polymers with different attractive properties, which direct the need for synthesizing and utilizing them for various applications [218]. Biopolymers can be obtained from plants, animals, and microorganisms or synthesized from different monomers [7]. The commonly available biopolymers, such as starch, cellulose, proteins, gluten, polyaniline, poly-lactic acid, and poly-butylene adipate-*co*-terephthalate, have widely been focused on preparing biofilms typically utilized in food packaging, tissue engineering and medical applications [103,146]. Various methods have been employed to prepare biofilms with different principles adapting numerous biopolymers [36,42,43,59]. Bio-based film preparation techniques and methods are unique and different based on the type of polymers, application areas and properties of the polymers, and the filler. The elementary biofilm preparation procedures, merits, and demerits of each method are discussed in the following section.

Table 1
Carbohydrate and other potential polymers with excellent film-forming capacities can be extracted, recovered, and produced from different natural sources. It is essential and crucial to derive biopolymers from their natural source and select the polymers for film preparation with different applications.

Biopolymer	Sources	References
Cellulose	Tomato plants	[153–155]
	Bactria	[156–158]
	Green algae	[159–161]
	Animals (tunicates)	[162–164]
Starch	Cassava	[165–167]
	Potato	[168–170]
	Rice	[171–173]
Protein	Whey (diary)	[174,175]
	Soya bean (oil extraction)	[176–178]
	Red lentil	[179–181]
	Moringa oleifera	[182–184]
	Vicica villosa	[185–187]
	Marine shell-fish wastes	[188–190]
Chitosan	Oyster shell	[191–193]
	Fungai	[105,194,195]
	Black solider fly	[106,196,197]
Poly (lactic acid)	Sugar cane	[198–200]
	Lactose	[201–203]
	Corn starch	[204,205]
	Wheat	[206,207]

Table 2
Carbohydrate and other potential polymers and their unique features are preferable as film-forming materials. These unique features may have a positive as well as a negative impact on the nature of the films and their application. In addition to these features are common features like biodegradability, non-toxicity, and bio-compatibility are possessed by all the polymers with film-forming ability.

Bio-polymer	Unique features	References
Cellulose	• 3D network structure • Optical transparency and tunable porous structure • High viscosity	[39,49]
Starch	• Processable as edible film or coatings • Abundancy • Non-toxic	[208,24]
Protein	• Excellent oxygen barrier properties • Ability to form gels, emulsions and foams • Valuable nutritional index • Good anti-microbial and anti-fungal properties	[209,210,211]
Chitosan	• Suitable carrier property for other materials • Large-scale availability and presence of practical groups for chemical adjustments • Good thermal processibility	[108,118,212]
Poly(lactic acid)	• Bio-compatible for foods • High transparency • Excellent thermal stability	[213–215]
Polybutylene adipate terephthalate (PBAT)	• Very tough and ductile • Superior mechanical and optical properties	[16,216,217]

3.1. Tape casting method (spread casting or knife-coating)

The tape-casting method involves casting the film-forming suspension on the polymer-covered tape-casting device. Doctor blades are used for uniform casting of the film-forming suspension [35,36]. A shifting tape casting apparatus with two doctor blades was used to cast a Poly (lactic acid) (PLA)/Mg solution on a glass plate [36]. The tape-casting method of biocomposite film preparation is displayed in Fig. 1. Different polymer compositions were used to prepare a film-forming suspension. Here, cellulosic fibers were used to prepare a fibrous suspension, blended with glycerol and starch to prepare a film-forming suspension at 71 °C. Then, the suspension was spread on the polyethylene terephthalate film-covered tape-casting device using two doctor blades [219].

A film-forming suspension of Soy protein isolate (SPI) and glycerol with different concentrations is formed and cast on polyester film using blades at 60 °C [35]. At 75 °C, at a heating rate of 1 °C/min, a combination of cellulose fibers, water, starch, and glycerol created a film-forming suspension in a thermal bath, and the suspension solution was cast on the plexiglass plate using three different doctor blade spacing [220]. The advantages associated with this method are the possibility of preparation of films with large dimensions, short drying times, and film thickness controlling ability, but its demerits are that it is costly in operating as well as production, and it is energy-intensive [221].

3.2. Solvent casting method

This method is a classical method of film preparation. A suspension of different components with proper viscosity will be prepared using different solvents and plasticizers. The film-forming suspension is cast on the Petri dish and dried without any external force except the temperature [37,59,222]. The solvent-casting method of biocomposite film preparation is demonstrated in Fig. 2. MgO/Ag nanoparticles with different concentrations mixed with polybutylene adipate terephthalate (PBAT) dissolved in chloroform to prepare PBAT/MgO/Ag solution. The solution was poured into a petri dish and allowed to dry in the open air at room temperature [38]. Biofilms are developed by mixing chitosan and ε-polylysine and heating the solution at 50 °C. The heated solution was coated onto glass and allowed to dry for 24 h in the open air [37]. E-Poly-L-lysine biofilm is developed in a way that a given amount of starch, glycerol as a plasticizer, and E-Poly-L-lysine mixture are stirred and heated at 95 °C, then incubated at 37 °C [223].

Bacterial cellulose-based composite films with carboxymethyl cellulose, glycerol, and yeast were developed using a concentration-dependent blending of the components and the blended components were exposed to vacuum and heat at 45 °C [59]. Glucomannan biofilms were formed by adding sulfonyl and sorbitol (surfactant and plasticizer) to the glucomannan solution that was stirred at 6000 rpm and 35 °C. The gel solution was put into a Petri plate and dried at 50 °C with a relative humidity of 11.4 %. MgO/Ag reinforced poly(butylene succinate-*co*-terephthalate) composite films was developed through a solution-casting method with varying concentrations of nanofillers distributed in chloroform dissolved poly(butylene succinate-co-terephthalate) and the mixture was poured and dried for 2–3 days on a glass plate. The films were approximately 20 μm thick [224].

Solvent-supported film preparation was used to develop nano-magnesium oxide-reinforced poly (lactic acid) films with the greatest improvement in tensile strength and oxygen barrier characteristics. A bird-type manual film applicator was employed for chloroform evaporation to generate consistent thickness films [225]. The advantageous part of using this method would be easily performed and protects denaturation materials from high operating temperatures, but the demerits of this method are high cost, long drying time, cannot produce a mechanically stable film, control of film thickness hard and it is impossible to produce industrial-scale films [224,225].

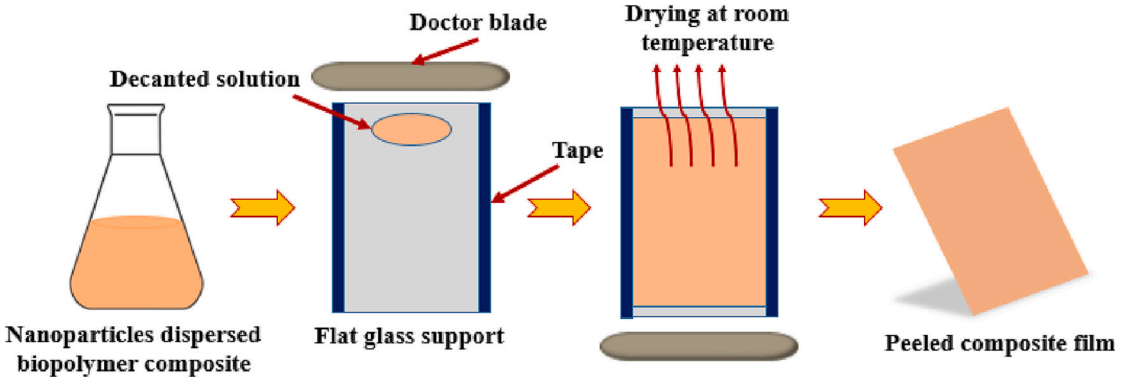


Fig. 1. Tape-casting method of biocomposite film preparation.

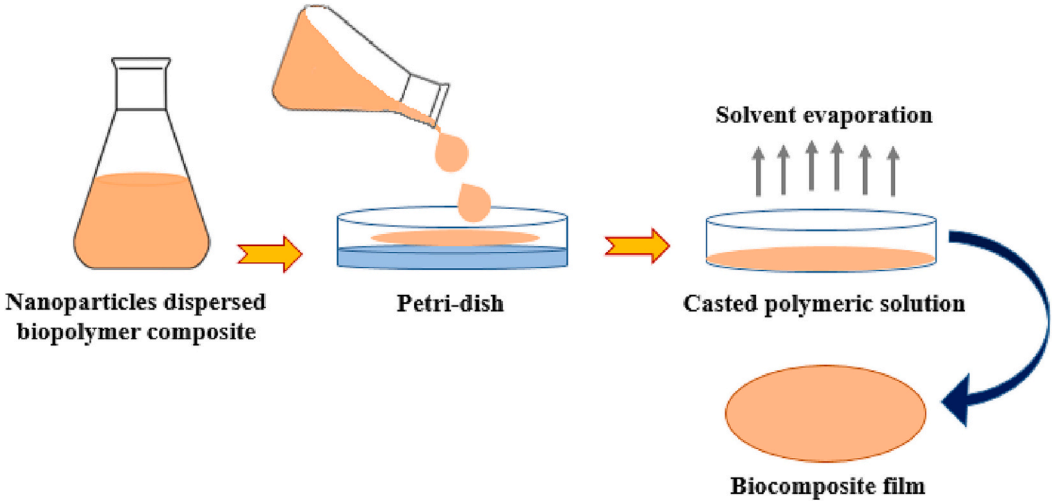


Fig. 2. The solvent-casting method of biocomposite film preparation.

3.3. Extrusion

One biofilm preparation method usually involves blending different components into a homogenized mixture, forming the extrusion strands of the compounded mixture using a single screw, pelletizing or calendaring the extruded strands, and conditioning the films at room temperature. It is a temperature-based process and usually, the temperature profiles associated with this method are known to be a feeder and die temperature [42,226]. The extrusion method of nanoparticles incorporated biocomposite film preparation is illustrated in Fig. 3. Egg white protein films were obtained using extrusion followed by calendaring the extrudates; a mixture of egg powder, water, and glycerol was used as a solution. The need for calendaring using drum dryers after forming extrudates using different feeders and die temperatures is to obtain a plastic-like structure [226]. Polyvinyl alcohol/starch/clay nanocomposite films were developed through an extrusion blowing system, but here, compounding the above mixture came before the blowing to form and conditioned pellets at 25 °C and 53 % relative humidity followed by extrusion blowing at five different temperature zones [13].

A biofilm obtained from corn starch and whey protein blends was successfully produced through extrusion. Here pellets of the above blend were produced using co-rotating twin screws with 7 different heating zones that lie between 70 and 110 °C and then a single screw extruded the pellets with 4 different heating zones to form film sheets, which were conditioned at room temperature [227]. Poly(butylene adipate-*co*-terephthalate) films can be developed through the extrusion casting method with a temperature profile of 140 °C and 150 °C for feeding and die zones, respectively. The screw rotation speed was 40 rpm [228]. A homogenized blend of polypropylene-chitosan-poly (lactic-acid) was extruded by a single screw that revolves at 25 rpm where the feeder and die temperature zones were 165 and 175 °C and the thickness of extruded film lies between 0.2 and 0.5 mm [229]. Tear-resistant, biodegradable, as well as flexible films of poly (lactic acid), were formed using different biopolymers and plasticizers through the extrusion technique, where the mixture was extruded at 11 different temperature zones that ended at a dying temperature of 140 °C, which then pelletized and blown at 150 °C, 50 rpm and melt pressure of 150 bar [133].

Poly (vinylidene fluoride) (PVDF)-based piezoelectric films were obtained through the extrusion method by mixing powder of PVDF/GO/PZT with alcohol and followed by drying to condition the composite. Then the conditioned mixture was granulated and extruded at 250 °C, which resulted in film thicknesses of 30–120 μm [40]. Uniformly glycerol, water, and alcohol-diffused starch were extruded with 10 different profile temperatures that ended at a dying temperature of 90 °C followed by pelletizing and hot pressing the extruded strands at 130 °C. The films were conditioned at 23 °C and 58 % of relative humidity [230]. The advantages of extrusion film processing over the classical

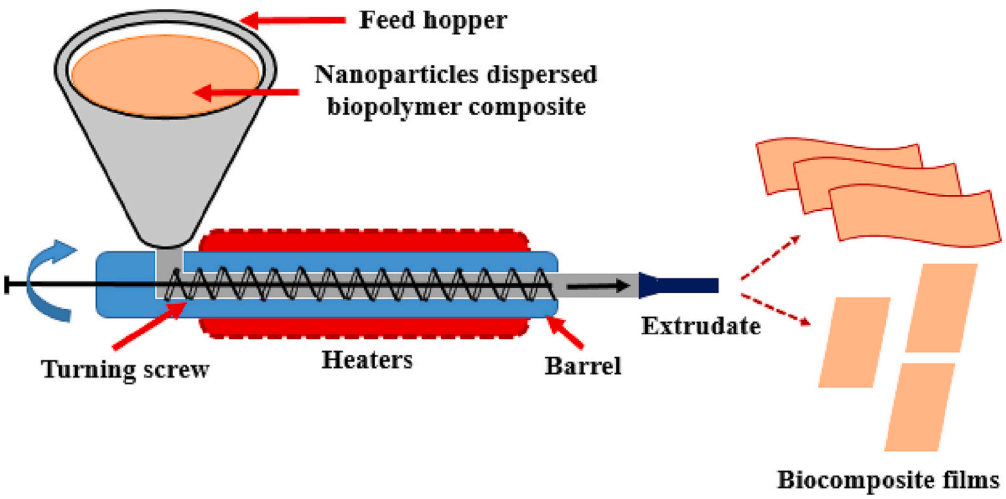


Fig. 3. Extrusion method of nanoparticles incorporated biocomposite film preparation.

ones are the films can be produced with large film thickness and possess high efficiency, flexibility, high tensile strength, commercial viability, dielectric constant, breakdown strength, and low cost compared to the solution casting method, but it is energy-intensive, the films produced through this method has low water permeability [13,40,133].

3.4. Mechanical and thermal compression

Thermal compression is one of the very well-known film preparation methods. It is known as the drying process because the films go through thermal compression and pressure. In low moisture content circumstances, thermoplastic biopolymers are heated above their glass transition temperature [7,43]. The mechanical and thermal compression method of nanoparticles incorporated biocomposite film preparation is illustrated in Fig. 4. Cellulose Nano fibril films were developed by drying the filtered cellulose suspension (wet films) through different drying methods and the dried film was finally compressed thermally at 120 °C and 1.1 MPa for 10 min [7]. Soy protein films were developed through a thermal compression in which soya protein and glycerol suspension were placed between two aluminum plates introduced to the press heated to 150 °C, and pressed at 12 MPa for 2 min [45]. Nano-fibrillated-cellulose-graphene (GNs/NFC) films can be developed from GNs/NFC suspension where a homogenized GNs/NFC suspension was obtained through filtration, and the filtered suspension (wet film) was dried at ambient temperature and further squeezed for 10 min at 150 MPa [231].

A citric acid cross-linked chitosan film was obtained through thermal and mechanical compression of a plasticized chitosan suspension which was placed and pre-heated between aluminum plates at 125 °C and pressed at 2.5 MPa for 2 min [44]. Liquid crystalline monomer-poly (vinyl alcohol) (LCM-PVA) dispersed films can be developed through filtration and mechanical compression of LCM-PVA suspension at 5 MPa and 160 °C for 5 min, then cooled up to room temperature [43]. The advantage associated with this method is to allow less time-consuming manufacturing, its ease of use, and the capacity to produce films without the need for solubilization, but due to high-temperature protein denaturation occurs for protein films [43,232]. A summary of biofilm preparation methods from different biopolymers is presented in Table 3.

Table 3
Summary of biofilm preparation methods from different biopolymers. The merits and demerits of the preparation methods are significant factors in determining the properties of films to be produced.

Film preparation methods	Advantages	Disadvantages	References
Tape casting	• Possibility of preparation of films with large dimensions • Short drying time • Film thickness controlling ability • Easy operation	• Energy-intensive • High operating cost	[36]
Solvent/ Solution casting	• Protects denaturation (especially for protein) from high operating temperature	• Long drying time • Lack of film thickness control	[39,37]
Extrusion	• Production of films with large film thickness • Production of films with flexibility, high tensile strength • Less time-consuming manufacturing	• Energy-intensive • Films produced through this method have low water permeability	[40,41,133]
Compression	• Simplicity • Ease of use and capacity to produce films without the need for solubilization	• Due to high temperatures, protein denaturation occurs	[43,232]

4. Improved characteristics of biopolymer-derived films using metal nanoparticles

As discussed in the previous chapter, film-forming biopolymers have their own unique and attractive properties to be utilized as film-forming polymers. However, these biopolymers also exhibited poor properties, making them not to be used as potential substitutes for petroleum-based plastics. For that matter, different researchers have implemented various scientific methods to tackle these poor properties of the biopolymers, for instance, blending with other biopolymers, using inorganic and organic fillers, i.e., nucleating agents. The most recent property improving the technique is using metal nanoparticles as property-enhancing agents.

4.1. Crystallization/nucleation property

In theory, polymer nucleation may be described as the initial random generation of a unique thermodynamic new phase that can irreversibly expand into a bigger-sized nucleus within the body of the metastable parent phase [233]. Any polymer's crystallization enhancement is affected by the type of filler and its size and form. The importance of enhancing the crystallization of a specific polymer widens its application area and its processibility (under thermal and stress) and increases the utilization rate of the polymers. The mechanism in shifting the crystallization properties of bio-polymers resulting from the incorporation of metallic NPs is usually related to the changes in the polymer's glass transition temperature (Tg) and melting temperature (Tm). The NPs would affect these specific properties by diverting the chain mobility and crosslinking density of polymer structures. The mechanism of property changes of biocomposite films is illustrated in Fig. 5.

Pure PLA was blended with copper nanoparticles. The crystallization enhancement was significant (from 76.9 % to 79.8 % with 0.043 wt% of Cu and 84.4 % with 0.074 wt% of Cu) [234]. As Nanofillers, graphene

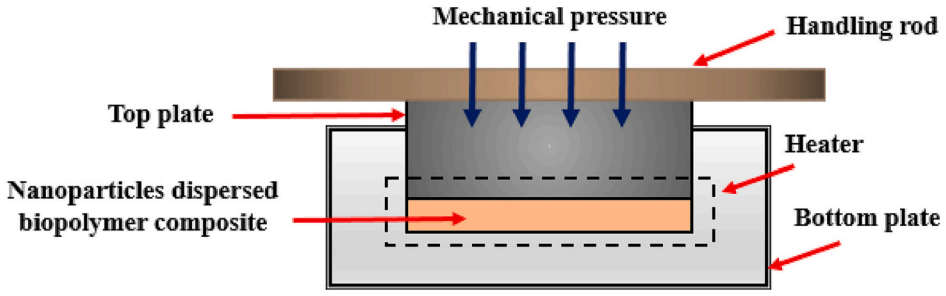


Fig. 4. Mechanical and thermal compression method of nanoparticles incorporated biocomposite film preparation.

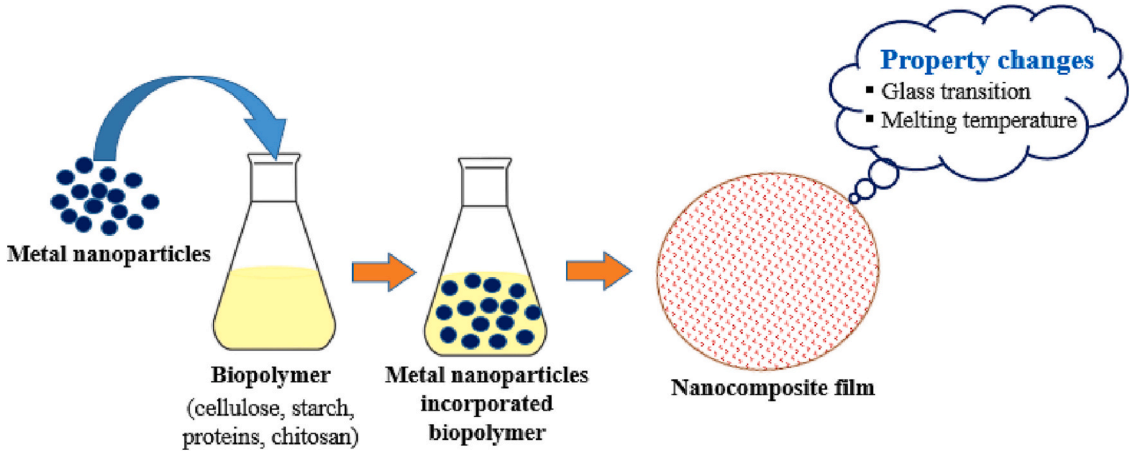


Fig. 5. Effect of metallic NPs on crystallization properties of biocomposite films.

oxide and multiwalled carbon nanotubes containing silver particles in various concentrations were employed to construct nanoparticle-dispersed poly (lactic acid) films. The inclusion of nanoparticles boosted the crystallization rate substantially, whereas the glass transition and melting temperatures of the PLA-based films remained almost constant [235]. The nano-ZIF-8@GO hybrids, which serve as a nucleating agent, were blended with poly(lactic acid) to increase the crystallization property and resulted in slightly higher glass transition temperatures (Tg) and high crystallization temperature (Tc), but the melting temperature (Tm) of the PLA nanocomposites is decreased [26]. A poly (lactic acid) film distributed with silver phosphate, zinc oxide, and nano-hybrids was created. The degree of crystallization rose dramatically from 2.8 % for the clean PLA film to 23.5, 23.2, and 25.4 % for Ag (2 wt%), Ag-Zn (2 wt%), and Ag-Zn (4 wt%), respectively [236].

The crystallinity of PLA increased by 95.6 %, 107.1 %, 118.6 %, 105.3 %, and 110.6 %, with the dispersion percentage of nano-Ag filler ranging from 0 to 15 wt%, respectively, and the crystallization temperature decreased by 2.7 °C in PLA nanocomposites with 15 wt% nano-Ag filler, but there was no significant difference in Tg with increasing nano-Ag content [99]. For a different dispersion rate of silver nanoparticles in PLA, a thermal analysis was performed with a heating rate of 0.1 °C/min. The result showed that the glass transition (Tg) for the pure PLA occurred at around 60 °C, and for the samples loaded with Ag nanoparticles, the glass transition (Tg) temperature proceeded at a higher temperature [237].

Zinc oxide nanoparticles (ZnO-NPs) dispersed with different loading rates in the poly (lactic acid) to develop a biofilm. The melting temperature (Tm) rose very slightly as ZnO NPs concentration increased, but Tc declined as a result of the decreasing influence of ZnO NPs on PLA crystallinity [238]. The nucleation effect of titanium dioxide (TiO_2) was studied on PLA/TiO_2 films, which resulted in an increment in crystallization temperature, no change in glass transition and melting temperatures as the amount of TiO_2 increased, but the degree of crystallinity was enhanced from 19.63 % (neat PLA) to 22.38 % (PLA/0.6 wt% TiO_2) [239].

By combining thymol and ZnO-NPs with poly (lactic acid)/poly (caprolactone)/thermoplastic starch ternary blends, novel thin sheets were created (lactic acid). The effect of zinc oxide nanoparticles on the crystallization property of the polymer was studied. The integration of ZnO-NPs resulted in a decrement in the cold crystallization temperature and a modest rise in the degree of crystallinity of PLA, which is ascribed to the presence of ZnO-NPs as the nucleating agent [240]. The melt mixing process was used to create polylactic acid-MgO nanocomposite films. The DSC results show that a small amount of 1 % MgO NPs increased the polymer's glass transition temperature (Tg), but higher reinforcement does not result in the expected increase in Tg, which could be due to agglomeration of MgO NPs at higher concentrations, and the Tm and Xc of blown NC films show no significant change with MgO reinforcement [225].

Poly(lactic acid) has a transition temperature (Tg) of 60.3 °C, while LDHs@PACu(II)/PLA nanocomposites have a slightly higher Tg. This can be attributed to the stronger interaction of PA-Cu (II) coatings to change the mobility of PLA chains related to the glass transition. The χ_c computed of LDHs@PA-Cu (II)/PLA nanocomposites are substantially higher than that of pure PLA as LDHs@PA-Cu(II) concentration rises, illustrating the nucleating action generated by LDHs@PA-Cu(II) (II). Furthermore, the T_m of LDHs@PACu(II) /PLA nanocomposites increases somewhat [241]. PLA film had a glass transition temperature of 58 °C, and the addition of cellulosic nanofiber (CNF) and Ag NPs had no effect. When compared to the clean PLA sheet, the crystallization temperature of nanocomposites rose by 1–2 °C. In contrast, the melting temperature of the nanocomposite was somewhat lower than that of PLA film [153].

The DSC scans revealed that ΔH_c is slightly greater than ΔH_m for all of the films, indicating that there is no crystalline phase in the crystal structure of the films based on the aforesaid relationship. Furthermore, adding MgO NPs had no notable effect on the Tg or crystallinity of the films [225]. The inclusion of ZnO NPs (5 wt%) enhanced the Tg, Tc, and Tm values of PLA/ACNC/ZnO composite films marginally due to the suppression of PLA chain motion. It was caused by the good dispersion of ZnO in composite films, and the *Xc* values of PLA/ACNC/ZnO composite films initially declined and subsequently climbed when the extra ZnO content was above 5 wt% [242]. The incorporation of TiO_2 nanoparticles enhanced the crystallinity percentage from 14.2 % to 18.2 %. Also, the addition of 2 and 4 vol% NPs, resulted in a modest decrease in the Tcc of the clean PLA from 130 °C to 129 and 128 °C [243].

Thermal analysis of PBAT/ZnO nanocomposite films was performed, resulting in a slight increment in Tg values of nanocomposite films than neat PBAT. In contrast, the addition of ZnO nanoparticles doesn't change the Tm but decreases the crystallinity degree (χc) [140]. When MgO@CTAB nanoparticles are dispersed (0, 1, 3, 5 and 7 wt%) in biodegradable poly(butylene adipate-*co*-terephthalate) (PBAT) films, the crystal structure of the film is affected. This effect can be explained so that the initial crystallization temperatures and Tc of PBAT nanocomposites shift to lower values, and the peak melting temperature (Tp) exhibits a decreasing trend. Still, the crystallinity values (χc) of PBAT are increased [64].

The DSC test results showed the synergetic effect of both multiwalled carbon nanotube and ZnO NPs on both PBAT and MPBAT. With the addition of 1 % of both NPs, the modified PBAT films exhibit lower crystallization and melting temperature [244]. Copper nanoparticles dispersed PBAT films were thermally analyzed and the degree of crystallinity increased as the concentration of Cu-NPs increased [245]. The

melting temperatures (Tm) of butylene adipate (BA) and butylene terephthalate (BT) segments of neat PBTA film are 58.8 and 114 °C, respectively. As AgNPs@SiO_2 loading increases, the melting temperature of the flexible BA segment becomes 57 °C, while the T_m of the rigid BT segment increases to 110 °C [246].

With the increased pattern of MgO/Ag NPs content from 0 wt% to 5 wt%, Tc of PBAT film increased from 74 °C to 81 °C and there was no change in the glass transition, and melting temperatures [247]. Improving the crystallinity (nucleation) property is a determining factor for utilizing the bio-polymers for different applications. In measuring the enhancement of the nucleation property of biopolymers, four essential parameters that should be considered are cold crystallization temperature (Tcc), degree of crystallinity (χc), and glass transition temperature (Tg) and melting temperature (Tm). It can be concluded that a biopolymer's nucleation property is enhanced with a positive change in those parameters. The effect of different NPs on the crystallization property of bio-based films is indicated in Table 4.

4.2. Mechanical property

Mechanical characteristics are physical qualities a substance shows when forces are applied. The modulus of elasticity, tensile strength, elongation, hardness, and fatigue limit are examples of mechanical parameters. These properties of biopolymers change dramatically with temperature, limiting their application area in industries. Therefore, enhancing the mechanical properties of any biopolymers is essential in that it helps produce eco-friendly materials that can resist any force applications. Many scholars have been using metal nanoparticles to enhance these particular properties of biopolymers. The following section discusses the effect of the metal oxide nanoparticles on the mechanical property of biopolymers.

The mechanical properties of cellulose film, leaf-extracted cellulose film, and cellulose nanocomposites were studied, which resulted in high elongation at the breakpoint as the concentration of bimetallic (Ag and Cu) nanoparticles increased, high tensile strength and tensile modulus observed up to some concentration of NPs but starts to decline as the concentration increases more [30]. The tensile strength (TS) was significantly increased for carboxymethyl cellulose film when ZnO-NPs were incorporated into the films. However, the TS and stiffness of the film decreased with the high content of NPs, but no significant change was observed in the flexibility of the film [28]. Incorporating metallic NPs involves shifting the mechanical properties of any polymeric biofilms. In such a way, adding NPs might create additional structure, i.e., cracks and holes, to the biopolymers, which either lowers the stress-withstanding ability or it might help in resisting stress on the composite films. In some cases, it might be inserted between cross-linked chains of the polymers, which results in the shifting elongation property of biofilms. The mechanical property changes of biocomposite films with metallic nanoparticles are shown in Fig. 6.

The incorporation of MgO up to 1.5 % had no discernible impact on the tensile strength of the prepared CMC/PVA film containing MgO [248]. The untreated and free paper sheets results reveal that metal deposition is unsuitable for strength properties. However, it causes a decrease in the tensile index. This undesirable observation is reduced by pre-treating paper sheets with chitosan (Ch) and cellulose diacetate (CDA) [249]. The CMC film's tensile strength (TS), elongation at break (EB), and elastic modulus (EM) were 42.8 MPa, 16.7 %, and 1.56 GPa, respectively. The addition of ZnO NPs did not affect the strength or stiffness of the CMC film, but the TS rose to 49.3 MPa when 0.5 wt% curcumin and 1.0 wt% ZnO were added [250]. The plain has a tensile strength and an elongation at break of Tensile strength and elongation at break of cellulose acetate (CA) film were enhanced from 35.5 MPa and 1.6 % to 49.2 MPa and 2.9 %, respectively, with 7 wt% Cu-MOF incorporation [251]. The addition of AgNPs on tempo-oxidized nanocellulose (TNC) significantly enhanced the mechanical property of the film, causing the AgNPs to occupy the TNC film's interspace [27].

Ghozali et al. (2020) [78] investigated the thermoplastic starch/metal oxide biocomposites prepared and the effect of these metal oxides on the mechanical property of the film. The tensile strength of TPS has been enhanced as the concentration of ZnO and TiO_2 NPs increases but declines as the loading rate maximizes. The ZnO-chitosan nanocomposite was produced and incorporated into starch films to enhance the mechanical property of the films and resulted in high tensile strength when the loading rate of NPs was 3.0 wt%. On the contrary, the elongation at break decreased [79] and Hajizadeh et al. (2020) [252] observed that the TS values of films loaded with both Ag-modified SiO_2 and TiO_2 NPs were considerably greater at all concentrations and the EB values of films containing SiO_2 and TiO_2 NPs considerably lower than those of pure starch film at all concentrations.

The addition of nano-SiO_2 greatly improved the tensile strength of potato starch films, with the 100 nm nano-SiO_2 providing the best tensile strength [26]. The results revealed that 0.5 % ZnO-NPs had no influence on the TS but dramatically increased the YM and EB values of the SC film. When the concentration of the NPs was increased to 1 %, the TS value reached 4.74 MPa while the YM value dropped to 17.31 MPa, and when the concentration of the NPs was increased to 2 %, the TS and EB grew even more, but the YM value reduced [253]. By adding 0–5 wt% of OEO, the tensile strength and tensile modulus of PSt-Ag NPs were significantly increased by up to 80.88 % and 88.63 %, respectively, due to the reinforcing action of homogeneously dispersed Ag-NPs in the matrix. Ag NPs aggregation at 7 % OEO reduced tensile strength and modulus [254].

Copper nanoparticle dispersed PLA film was studied and found to have a greater Cu content (0.082 wt%), lowering the EB value by 14.9 wt % compared to PLA-Pr. There are no statistically significant variations in Young's modulus. Copper nanoparticles resulted in a significantly greater strain at break [234]. PLA/PBAT composite film with TS of 14.5 MPa was analyzed and the TS of PLA/PBAT films rose to 23.4 ± 3.9 and 26.9 ± 2.8 MPa when $ZnONP^{ZA}$ and $ZnONP^{ZC}$ were added, respectively but increased to 16.8 ± 3.7 MPa when $ZnONP^{ZN}$ was added. The modulus of elasticity, on the other hand, (EM) (stiffness) increased considerably, but elongation at break (EB) was significantly decreased, in which the EB (flexibility) of PLA/PBAT film was 199.9 ± 32.2 %. But when $ZnONP^{ZA}$, $ZnONP^{ZC}$, and $ZnONP^{ZN}$ were incorporated into PLA/PBAT film, it decreased to 118.1 ± 23.9 %, 121.8 ± 14.1 %, and 142.3 ± 26.8 %, respectively [255].

When 1 wt% LDHs@PA-Cu is added to LPCP1, exhibiting a 53.0 % improvement in elongation at break and an 18.9 % increase in tensile strength when compared to pure PLA (II). Still, it shows a decrement in TS and EB when the LDHs@PA-Cu(II) concentration exceeds 5 wt%, yet better mechanical properties than pure PLA [241]. The tensile strength of pure PLA film is 4.2 MPa. After the incorporation of 0.25 wt% of NiO with PLA, the tensile strength increased to 7.12 MPa, and the maximum value of tensile strength of 16.54 MPa was achieved at 1 wt% of NiO [256]. Zinc oxide nanoparticle was dispersed in Poly (lactic acid). Its effect on the mechanical property was investigated, which resulted in declining tensile strength as the ZnO loading rate increased. PLA with 1

Table 4
Effect of different NPs on crystallization property of bio-based films.

Polymer and incorporated NPs	Crystallization property	Reference
Poly (lactic acid) and Cu	• X_c from 76.9 % to 84.4 % at low concentrations of NPs	[234]
Poly (lactic acid) and Ag	• Significant change in crystallinity occurred, yet there was no change in T_g	[99]
Poly (lactic acid) and TiO_2	• Degree of crystallinity was enhanced from 19.6 % to 22.4 %	[239]
PBAT and MgO/Ag	• T_c increased significantly, but there was no change in T_g and T_m	[146]
PBAT and ZnO	• Slight change in T_g, T_m was not affected and X_c was decreased	[140]

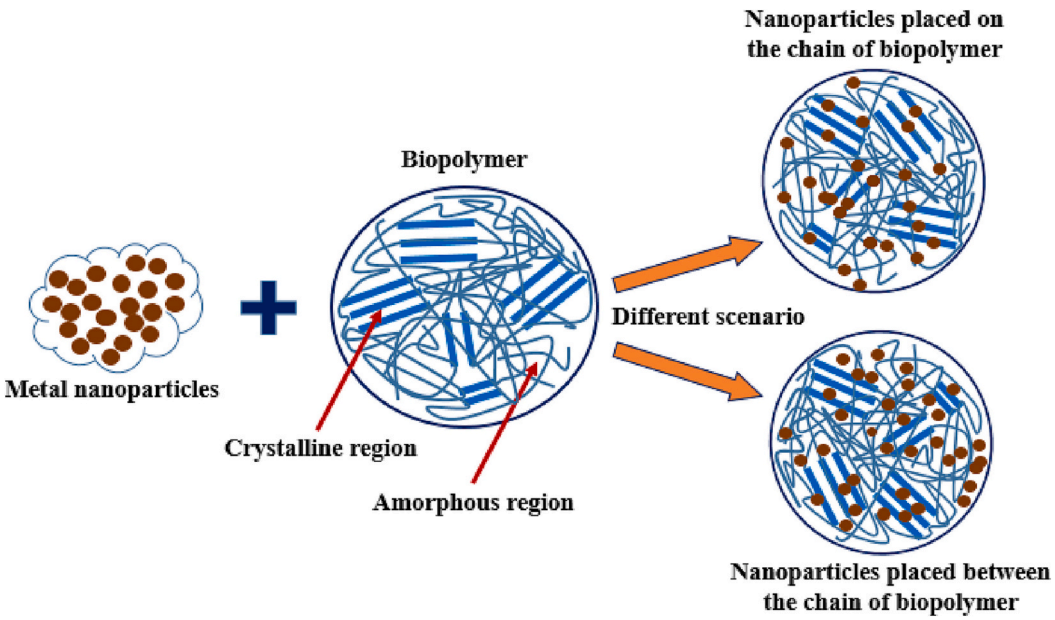


Fig. 6. Mechanical property changes of biocomposite films with metallic nanoparticles.

% of ZnO shows the highest PLA elongation at break and Young's modulus [257].

The incorporation of TiO_2 with PBAT and thermoplastic cassava starch (TPS) blended films was performed to enhance the mechanical property of the film. The results showed that small but YM and TS increased with the incorporation of TiO_2 [258]. MgO@CTAB nanoparticles dispersed (0, 1, 3, 5, 7 wt%) in biodegradable PBAT films, and the TS and EB (%) were increased up to optimal loading of the nanoparticle (3 wt%) but decreased as the loading rate increased, but Young's Modulus increased as the loading rate increases [64]. Multiwalled carbon nanotube-zinc oxide (MWCNT-ZnO) NCs were synthesized and dispersed in PBAT and its derivative. The MPBAT/MWCNT-ZnO nanocomposite film displayed the best mechanical performance at 0.2 % MWCNT-ZnO. (17.74 % increase in tensile strength, 22.17 % in yield strength, and 14.29 % in elongation at break) [244]. The tensile strength and elongation of Cu NPs incorporated PBAT film increase with 1 % load NPs but not in the elastic range [245]. Mechanical properties of Starch/PBAT/AgNPs@SiO_2 (SPA) films can be summarized as TS and EAB values increasing (2 wt%) and then decreasing (> 2 wt%) with increasing AgNPs@SiO_2 loading [246].

The results for E, σb, and εb for PBAT/SiO2-EO initially grow and then plateau, but the highest comprehensive attributes occurred for 0.6 vol%, encompassing stiffness, strength, and elongation at break values of 59 MPa, 35 MPa, and 675 %, respectively [259]. With 5 wt% incorporation of ZnO/Rgo nanocomposites into the PBAT film, the TS and elastic modulus increase from 7.65 MPa and 5.31 MPa (neat PBAT film) to 27.43 MPa and 9.36 MPa, respectively [260]. A significant enhancement in the mechanical properties of PBAT film was found at the loading of 3 wt% MgO/Ag. As the content of NPs increases, it tends to form big agglomerations in the composite film [247]. Because of its hydrophilic character, the chitosan film exhibited the lowest tensile strength of 8.29 MPa compared to the other produced films. The tensile strength of CCZ2 with 5 % (*w*/w) ZnO was approximately 60 % greater than that of CCZ1 [261]. The addition of NiO-NPs influenced the mechanical characteristics of chitosan film significantly. This resulted in an increase in tensile strength, Young's modulus, and a decrease in elongation at a break of up to 6 % [29].

To investigate the impact of metal oxide (GO, MgO, TiO_2, and ZnO) nanoparticles on the mechanical properties of chitosan film, metal oxides were incorporated into the chitosan film. GO (0.1–5 %) exhibits enhanced TS. The TS and elastic moduli of 5 % MgO incorporated chitosan film is 86 % higher and 38 % compared to neat chitosan films, respectively. After introducing 30 % TiO_2, the tensile strength of the CS-glycerol films increased 5.83 times. Furthermore, the elastic modulus of these chitosan-glycerol-TiO_2 nanocomposite films was 11.76 times greater than that of the chitosan-glycerol films. With loading concentration (0.5–4 %) of ZnO elastic moduli of bio-based films was improved [262]. Rodrigues et al. [263] reported the mechanical effect of ZnO-NPs on chitosan film, resulting in enhanced elongation, Young's modulus, and tensile strength that 8 wt% of NPs. Whereas chitosan film containing TiO_2 shows high Young's modulus (348.13 MPa), tensile strength (TS) (20.76 MPa), and elongation at break (% EB) (37 MPa) compared to neat chitosan film [264]. The effect of different NPs on the mechanical property of bio-based films is displayed in Table 5.

4.3. Thermal stability

The capacity of a polymeric substance to withstand the effect of heat is characterized by its thermal stability. The polymer structure, kind of covalent or noncovalent bonds, and degree of unsaturation are all factors to consider when dealing with biopolymers' thermal stability [265]. Bringing out multifunctional biopolymer products to enhance thermal stability is as important as producing biopolymer products [266]. Recently, using NPs to enhance the thermal resistance of polymers is becoming preferable due to the significant impact of the metal and metal oxide NPs. The following research reports address how the NPs incorporate with the polymers and how they affect the thermal stability of the polymers. The thermal stability of biocomposite films could easily be altered by incorporating thermally active metallic NPs. Often, the metallic NPs lower the thermal stability of composite films by increasing their thermal conductivity and decreasing their resistivity to thermal factors. The effect of incorporated metallic NPs on the thermal stability of biocomposite films is depicted in Fig. 7.

Leaf-extracted cellulose (LECF) and green synthesized bimetallic nanoparticles, namely Ag and Cu, were mixed to prepare nanocomposite films, and their thermal stability was analyzed. The thermal stability drastically decreased from 50 to 100 °C as the moisture was released from the film, and then no variations were found up to 350 °C for all films prepared with different concentrations of bimetallic NPs. The neat LECF exhibited different thermal properties after 350 °C, but NPs dispersed films showed different thermal stability around 300 to 350 °C due to thermal stability brought by the nanoparticles [30].

Table 5
Effect of different NPs on the mechanical property of bio-based films.

Polymer and incorporated NPs	Mechanical properties			Reference
	TS	EAB	YM	
Cellulose and Ag/Cu	• Started to decline as the concentration of NPs was high	• Increased at high concentration of NPs	• NA	[30]
Chitosan-starch blend and ZnO	• Increased with 3 % incorporation of NPs	• Declined as the loading rate of NPs increased	• NA	[79]
PLA with Cu	• NA	• Lowered by 15 % compared with neat PLA	• No change	[234]
Chitosan and TiO_2	• Increased	• Increased	• Increased	[264]

NA – not available.

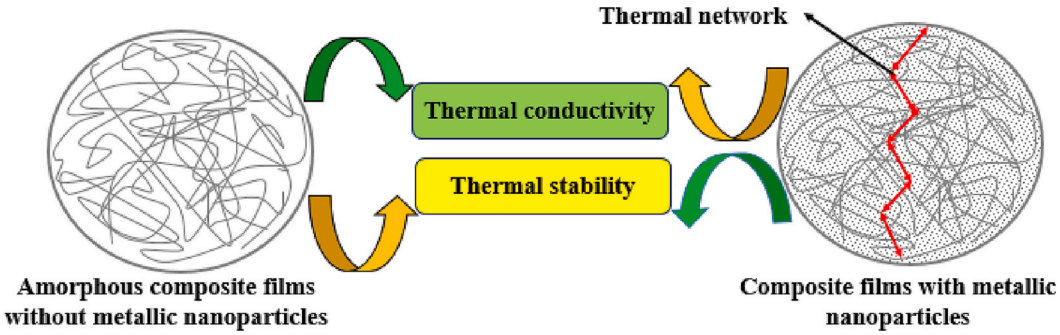


Fig. 7. Effect of incorporated metallic NPs on the thermal stability of biocomposite films.

Priyadarshi et al. [28] studied CMC films' thermal stability, which resulted in a two-step weight reduction strategy: 1) moisture removal and 2) decomposition of glycerol and CMC polymer matrix. Adding ZnO-NPs does not substantially differ from the CMC-based films' thermal degradation pattern compared to bacterial cellulose films. Cu-MOF nanoparticles dispersed cellulose acetate (CA) film's thermal properties were analyzed. As the concentration of Cu-MOF increases, the onset degradation temperature (T_{onset}) declines. At the same time, the maximum degradation temperature (T_{max}) was not much affected. Compared to the neat CMC film, the maximum decomposition temperature ($T_{0.5}$) of CMC/ZnO film decreased slightly. However, there was no significant change in T_{onset} [267].

In the case of biofilms prepared using the composite of Ag-NPs and sugar palm starch, the degradation temperature rose as the quantities of Ag-NPs increased because of their (Ag-NPs) excellent heat-storage capacity [268]. Zhu et al. (2021) [269] studied how ZnO-NPs and SiO_2-NPs alter the thermal stability of the films. The T_{max} observed for starch-ZnO, starch-SiO_2, and starch-ZnO-SiO_2 films were 322, 318, and 322 °C, respectively. Here, the ZnO-NPs dispersed starch film showed maximum thermal stability than SiO_2-NPs. However, both NPs exhibited higher thermal stability when compared to granules of starch (314 °C) and the neat film (318 °C). The pure starch–chitosan films presented a typical endotherm from 50 to 150 °C, characteristic of water loss. The dispersion of the TiO_2-NPsinto the starch–chitosan film does not interfere with the thermal behavior of the composite films, according to Vallejo-Montesinos et al. (2020) [270].

In the temperature range of 300 to 382 °C, neat PLA film lost 96 % of its weight, corresponding to removing the ester group. When ZnO-NPs dispersed, the T_{onset}, T_{50}, and T_{endset} values of PLA films showed a decrement pattern [238,271]. However, TiO_2 -NPs dispersed film showed a higher decomposition temperature when compared to pristine PLA film. Still, there was no significant change with adding more concentrations of TiO_2-NPs [239]. Yu et al. (2021) [123] reported that neat PLA's T_{max} was 379 °C but slightly increased when it was incorporated with acetylated cellulose nanocrystals. However, ternary composite film T_{max} values decreased and shifted further with a high concentration of ZnO NPs. The addition of TiO_2 to PLA provides no change in the T_{onset}, but alters the T_{max}, while the Ag-NPs dispersion also decreases the thermal resistance of the film [272].

The decomposition curves of MgO@CTAB with PBAT shift to lower temperatures with the increasing loading of MgO@CTAB [64]. Zhang et al. (2021) [224] also stated that the initial breakdown temperature was also reduced from 377 to 322 °C due to the catalytic effects of MgO on PBAT matrix. In contrast, the weight loss of PBAT showed a decrement pattern from 420 to 560 °C, increasing MgO and Ag nanoparticle content in the ternary nanocomposite. This might be the synergetic effect of scattered nanoparticles in PBAT films. At 421 °C, the neat PBAT lost 1 % of its weight, while PBAT/Cu film presented a weight loss of around 3 %. The final thermal decomposition was 98.9 %, 97.5 %, 95.4 %, and 96.8 %, respectively, to pure PBAT matrix, nanocomposites of PBAT/Cu with the loading of Cu-NPs 1, 3, and 5 % at the temperature range 420–427 °C [245]. It can be noticed that the thermal decomposition percentage was decreased than the neat PBAT film when the composite was formulated with 3 % Cu-NPs.

When 6 % NiO-NPs were incorporated into chitosan film formulation, the T_{max} increased to 257 °C from 232 °C, i.e., for neat chitosan. It shows the enhanced intermolecular interactions between chitosan chains and NiO-NPs [29]. Zahiri et al. (2021) [273] performed the thermal stability analysis of ZnO-NZnO-NPs-loaded chitosan films. The result showed that at a lower concentration of ZnO-NPs the film's thermal stability was improved. Still, as the ZnO-NPs concentration increased, the thermal stability of the film started to decline. It could be concluded from the results discussed that integrating metal nanoparticles into biopolymer films might result in the increment or decrement pattern of thermal stability according to the nature of polymers and their interactions with the nanoparticles. The thermal stability of biopolymers could be adjusted during the processing based on their applications. However, developing thermally stable bio-polymeric films is directly related to creating process-able films with good enhanced properties. The effect of different NPs on thermal stability of bio-based films is presented in Table 6.

4.4. Barrier properties

Barrier properties include permeability of gases, optical barrier properties, and water vapor permeability, i.e., related to the film materials' qualities, such as the component chemicals' hydrophilicity or hydrophobicity [274–276]. To avoid degradation, food packaging materials must have low permeability to moisture or gas molecules. The water barrier properties of films can be assessed by measuring water

Table 6
Effect of different NPs on the thermal stability of bio-based films.

Polymer and incorporated NPs	Thermal stability	Reference
Chitosan and NiO	• T_{max} increased by 25 °C	[29]
PLA and ZnO	• T_{max} shifted to lower temperatures	[123]
Starch and Ag	• Degradation temperature increased at a high loading rate of NPs	[268]
PBAT and MgO	• Decomposition curves shifted to lower temperatures	[64]

vapor permeability (WVP), moisture absorption, and swelling ratio. The effect of active metallic NPs on the barrier properties of polymeric films essentially depends on the dispersion, size, and type of NPs. The hindering and blocking the activity of the films that are raised from the structural changes resulted from the incorporation of metallic NPs. The NPs involve lowering the movement of water and air molecules into the structure of the films and blocking the penetration of UV-light. The Effect of incorporated metallic NPs on the barrier properties of biocomposite films is illustrated in Fig. 8.

With GO-NPs loading, the permeability coefficient of O_2 improved dramatically, successfully preventing O_2 penetration into the cellulose nanocomposite films [277]. The produced alumina nanocomposites improved the moisture resistance of the CMC-based film. As a consequence, the nanoparticle-based films that were produced demonstrated strong barrier characteristics against oxygen infiltration [278]. Uncoated paper's WVP was determined to be 11.7410^{-10} g/m^2 Pa. Compared to uncoated paper, the WVP of CMC/CNC@Ag-NPs coated paper was reduced by approximately 32 %. It could be further enhanced by increasing CMC/CNC@Ag-NPs content. Similarly, the air permeability of paper was decreased from 1363 L/min m^2, i.e., for uncoated CMC paper when the films contained CNC@AgNPs, as reported by He et al. (2021) [279]. The clean CMC film had a WVP of 2.04–9 g/m^2 Pa. Adding ZnO-NPs to the CMC films lowered the WVP and water contact angle considerably [28]. The WVP of presiten cellulose acetate films is 8.86 g/h.Pa, however, lowers considerably to 5.82 g/h.Pa for CA/7 % Cu-MOF films [251].

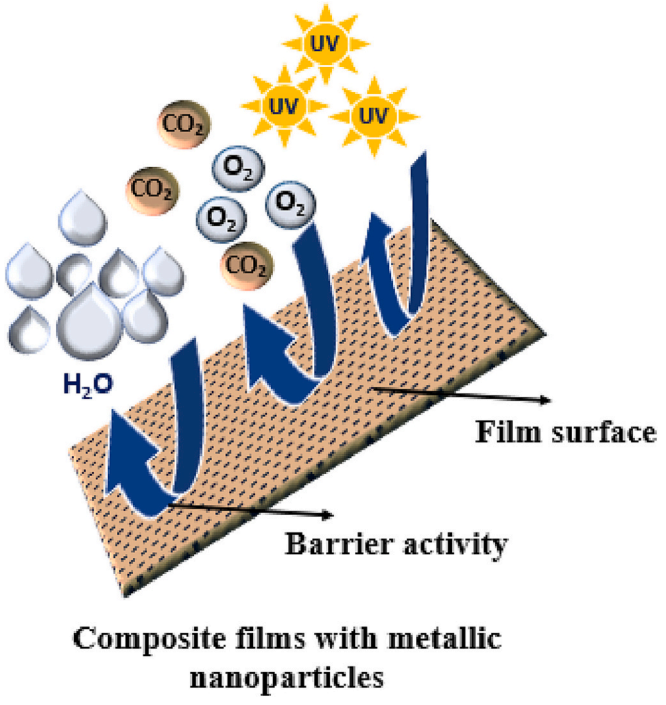


Fig. 8. Effect of incorporated metallic NPs on barrier properties of biocomposites films.

Semi-refined iota carrageenan's WVP was reduced as more SiO_2 and ZnO-NPs were added. However, compared to films with only one kind of nanoparticle, films containing a mix of SiO_2–ZnO nanoparticles had a lower WVP value [280]. Roufegarinejad et al. (2022) [281] reported that the WVP of neat SPI film was 49.11 × 10^{-10} g/s.Pa and it significantly decreased by incorporating TiO_2 and CuO-NPs by increasing their concentrations. A similar outcome was seen by Lee et al. (2021) [282] for chicken skin gelatin tapioca starch composite film prepared with ZnO-NPs. The WVP of the gelatin film was decreased from 3.94 × 10^{-9} to 3.36 × 10^{-9} g/m^{2}Pa after reinforcing the gelatin matrix with magnetic iron oxide nanoparticles from 0 to 10 % [283].

The permeability of the alginate film is 1.48 × 10^{-9}g/m^2.Pa, following the integration of sulfur nanoparticles, a substantial decrease in WVP values was found for the resultant nanocomposite films up to a concentration of 2 wt% nanoparticles. The WCA of the clean alginate film, on the other hand, was 56.14°, which increased when sulfur nanoparticles were added [28]. The WVP and WCA were used to determine the water vapor barrier and surface wettability characteristics of the alginate-based films, which resulted in decreasing and increasing trends, respectively, as the CuS-NPs were incorporated with the film [267]. As the fraction of ZnO nanoparticles increased, the water absorption capability of the Soy protein-based film decreased. As a result, they lost their superabsorbent properties [284]. The WCA of the starch/alginate films, i.e., control films, was 22.35°, which has a high level of hydrophilicity. The addition of g-C_3N_4 or Cu5%-g-C_3N_4increases the WCA to 47.26° and 49.86°, respectively. On the other hand, the WVP of the neat film changed from7.5 × 10^{-13} to 4.13 × 10^{-13} and 3.05 × 10^{-13} kg/m^2.s.Pa, respectively when incorporated with g-C_3N_4 and Cu5%-g-C_3N_4 [285]. The PVA/S-TiO_2 film was found to have significantly higher moisture content (MC), while the PVA/S-ZnO film has low MC value than PVA/S-control [286].

Oxygen transmission rate (OTR) and WVP values of pure PLA were 69.42 μm·mL/m^2·day·mbar and 1.14 × 10^{-11} g/m^2·Pa·s, respectively. The OTR and WVP values of the PLA/ACNC/ZnO ternary composite films declined further when the ZnO nanoparticle loading was increased to 5 % by weight [242]. PLA film reinforced with 9 % ZnO decreased WVP up to 40 % and OTR up to 33.5 %, while at 15 % ZnO loading decreased the WVP up to only 20 % and there was no change in OTR [287]. The PLA/PBS film had a low water absorption capacity due to a porous surface created when ZnO was incorporated into the film PLA/PBS/ZnO.1 showed the highest values in the swelling test. [288]. The pure PLA film's OTR was reduced from 1439.07 to 841.20 cc/m^2.day. Pure PLA WVP reduced from 8.24 to 3.96 g/m^2/day, with a rising trend of NiO-NPs [256]. ZnO-NPs dispersed PLA film significantly enhances water solubility and swelling capacity compared to pure PLA film [224].

Oxygen permeability and WVP values altered with increasing Ag@SiO_2-NPs loading in starch/PBAT films. The minimum oxygen permeability and WVP values were observed at 2 wt% loading Ag@SiO_2-NPs [246]. But, the oxygen and CO_2 permeability increased with increasing TiO_2-NPs in PBAT-based film and reached maximum permeability at 3 % TiO_2-NPs [258]. The oxygen and WVP coefficients were lower in comparison to clean PBAT. TiO_2-NPs and PBAT/hybrid nanocomposite fillers had little effect [289]. The inclusion of TiO_2/Ag-NPs reduced the WVP and OTR. When compared to PBTA-0 film, the WVP and OTR of PBTA-5 film were lowered by roughly 37 % and 71 %, respectively [290].

The clean chitosan film had a WVP of 0.59 to 0.03 g/m^2.Pa.s, which reduced to 0.51 to 0.03 g/m^2. Pa.s following the addition of tannic acid. It was drastically lowered further to 0.46 to 0.03 g/m^2.Pa.s after integrating 1 wt% TiO_2 [291]. Water vapor transmission and permeability were investigated in TiO_2-dispersed chitosan (CS) film and decreased both barriers as the concentration of TiO_2 increased [292]. Neat chitosan film with 2.41 ± 0.32 × 10^{-6} g/m·s·Pa WVP, but the addition of NiO-NPs at high concentrations had a widespread effect on lowering WVP values [29]. Pristine chitosan film with oxygen permeability and

WVP of 0.18 × 10^{-16} mol m/m^2.s.Pa and 1.54 × 10^{-11} mol m/m^2.s.Pa was incorporated with ZnO-NPs. Incorporating ZnO-NPs negatively affects both properties [293]. Similarly, the presence of Ag-NPs increased the chitosan-based films' WVP, as per the report of Shankar et al. (2015) [228]. The oxygen permeability and WVT of chitosan-based films dispersed with reduced graphene oxide and Ag-NPs were smaller than that of CS, CS/rGO. In general, the barrier properties of the films are enhanced, which means that the WVP and OTR coefficients are minimized compared to neat film. Improving the barrier qualities of bio-based films is critical for keeping meals fresh, unpolluted, and nutritious for an extended period. The effect of different NPs on the barrier properties of bio-based films is showed in Table 7.

4.5. Antimicrobial activity

Naturally, the anti-microbial activity of bio-based films is the capacity of the specific biopolymers to act against microbial activities when used in different applications. In this context, biopolymer-based films have no significant antimicrobial activities except those from chitosan [295,296]. Therefore, incorporating organic or inorganic active components into the biopolymers is crucial for enhancing the application of biofilms with a broad range of antimicrobial properties. The anti-microbial activity of metallic NPs incorporated in polymeric films work in a way that the NPs involved in attacking the cell wall of microorganisms, which leads to microbial mortality. Besides, the charges of the NPs incorporated play a vital role, specifically for Gram-positive and Gram-negative bacterial species. The anti-microbial activity of incorporated nanoparticles in the composite films is illustrated in Fig. 9.

The cellulose nano crystals-based films exhibited the highest inhibition zone against *E. coli* RB and *S. aureus* when the Ag_2O than ZnO and TiO_2 were incorporated [297]. Roy et al. (2020) [250] studied the effect of ZnO and curcumin added to the CMC-based films against foodborne pathogenic bacterial species, such as L. *monocytogenes and E. coli*. The investigation revealed that ZnO-NPs showed good antibacterial activity, whereas curcumin exhibited a bacteriostatic effect for the studied pathogens. The cellulose/elastomeric polymer bitumen-based hybrid biofilms with Ag-NPs displayed more bactericidal activity for Gram(−) bacterial species than Gram(+) [298].

Madivoli et al. (2022) [299] observed that Ag-NPs@cellulose nanofibers composite films have an antagonistic effect on different bacteria, namely *P. mirabilis, B. subtilis, C. albicans, S. aureus, P. aeruginosa* and *E. coli.* However, more potency was measured against *B. subtilis*. About 96 % of the inhibition rate was determined for *S. aureus and E. coli*, while 51.2 % was observed for *C. albicans by* ZnO-NPs@Zn^{2+}/Cel composite films under colony count test for six hours [300]. The structure of bacteria, such as *L. innocua* and *E. coli* was altered and also showed a high rate of antibacterial activity by CuO-NPs dispersed with cellulose-based biofilms [301]. The TiO_2-NPs and MWCNTs resulted in a maximum inhibition zone against *E. coli* than *C. albicans* and *S. aureus* when incorporated into cellulose-based films [302].

Table 7
Effect of different NPs on the barrier properties of bio-based films.

Polymer and incorporated NPs	Barrier properties	Reference
Starch/PBAT and $Ag@SiO_2$	• Minimum oxygen permeability and WVP at 2 wt% loading of NPs	[246]
Chitosan and Ag	• WVP of the film increased	[294]
PLA and ZnO	• With 9 % ZnO decreased WVP up to 40 % and OTR up to 33.5 %	[287]
Gelatin and FeO_3	• WVP of the gelatin film decreased from 3.9 × 10^{-9} to 3.4 × 10^{-9} g/m^2Pa	[283]
Cellulose and alumina NCs	• Strong barrier characteristics against oxygen infiltration	[278]

Peighambardoust et al. (2019) [303] investigated the individual and synergetic antibacterial effect of Ag, CuO and ZnO-NPs dispersed into starch-based films. According to the findings, the synergistic impact was four times greater for *S. aureus* and two times more for *E. coli* than the individual effect. Besides, Ag-NPs resulted in a maximum inhibitory effect for both bacterial species among the nanoparticles used. The antimicrobial activity of ZnO-chitosan nanoparticles dispersed starch film was analyzed. The film exhibited positive antibacterial activity against both gram-positive and gram-negative bacteria [292]. The agar diffusion method investigated the antimicrobial activity of ZnO-NPs dispersed starch films against *S. aureus* and *E. coli* was investigated by [304]. The film exhibited an inhibition zone of 5 ± 0.1 and 4 ± 0.1 mm against *S. aureus* and *E. coli*. Antibacterial activity of MgO dispersed starch-based films was 4–6 mm zone of inhibition against *E. coli* and *S. aureus* [305]. Gelatin/starch/ZnO-NPs film was tested against *S. aureus and E. coli*, resulting in 67.28 ± 17.28 and 85.30 ± 18 mm^2 zones of inhibition, respectively [306].

The antibacterial activity of Chitosan-based films incorporated with ZnO-NPs was studied against *S. aureus* and *E. coli.* The zone of inhibition increased from 0 to 22.85 ± 6.81 and 0 to 23.51 ± 3.12 mm for *S. aureus* and *E. coli,* respectively [125]. The NiO-NPs incorporated chitosan films inhibited the growth *S. aureus* and *S. typhimurium* [29]. The antimicrobial activity of Ag-NPs/PLA composite films observed was 31.7 and 35.6 mm for *S. aureus and C. albicans*, respectively [237]. The synergetic antimicrobial effect of ZnO/rGO on PBAT films against *E. coli* and *S. aureus*was analyzed. The measured maximum inhibition zone for *E. coli* was 19.2 ± 0.81 mm and for *S. aureus* was 20.0 ± 0.38 mm [260]. The broader the inhibition zone, the greater the antibacterial activity of the films. Generally, the antimicrobial activity of metal and metal oxide nanoparticles is related to how efficiently these particles inhibit the growth of different bacterial species. The microbicidal effect depends upon the size and shape of NPs, ions releasing ability of the NPs, the cell wall composition of the bacteria, and the interaction way between the films and the bacteria. Based on their response to the antimicrobial test, the nanoparticles incorporated in biofilms could be applied for bacteriostatic or bactericidal purposes. The effect of different NPs on the antimicrobial properties of bio-based films is presented in Table 8.

5. Constrains for developing metal nanoparticles dispersed biofilms

In recent decades, metal or metal oxide nanoparticles have been utilized in different research areas to achieve high-end applications. Using those nanomaterials as fillers to enhance the limited properties associated with biopolymers is unavoidable. Nowadays, it is a very attractive research area due to its positive impact on improving the properties of biofilms [307,308,309,310]. Although all their significant impact in enhancing the properties of biobased polymer-driven films, they exhibit some limitations. There are some limitations commonly existing for most nanomaterials. Also, some biofilm developmental constraints are associated with specific nanoparticles. A few common limitations include the migration effect [99,153], toxicity, and, the incompatibility nature of nanomaterials [244]. The specific constraints possessed by particular nanoparticles include weak photocatalytic activity, limited to enhance the flexibility of composite films [140], poor processability, formation of aggregates [26] and toxicity to prokaryotic cells [303]. For instance, GO failed to enhance the glass transition and melting temperature of PLA film [235] and ZnO-NPs have limitations in encompassing reactive oxygen species and reactive nitrogen species, which are more hazardous [240]. Dealing with the above-mentioned limitations of different metal and metal oxide nanoparticles is crucial for improving their processibility and producing compatible biofilms for various applications.

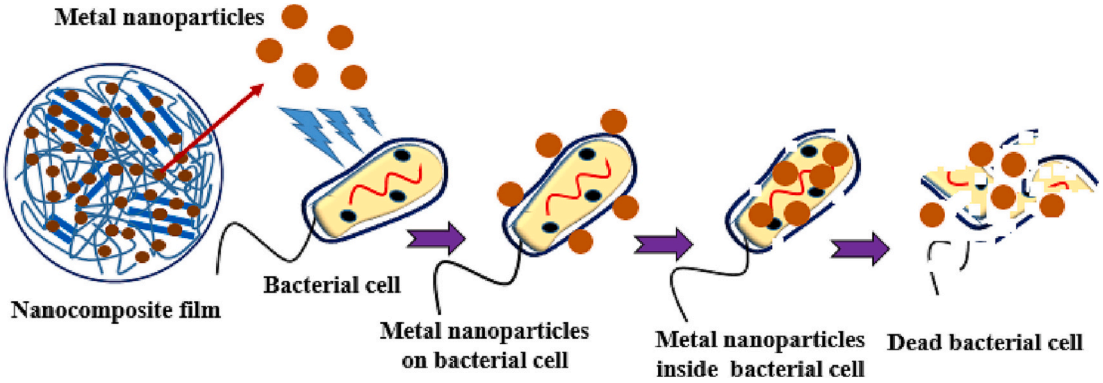


Fig. 9. Anti-microbial activity of incorporated nanoparticles in the composite films.

Table 8
Effect of different NPs on the anti-microbial properties of bio-based films.

Polymer and incorporated NPs	Anti-microbial properties	Reference
Cellulose and ZnO-NPs@Zn^{2+}	• About 96 % of the inhibition rate was determined for *S. aureus* and *E. coli*, while 51 % was observed for *C. albicans*	[300]
PBAT and ZnO/rGO	• Maximum inhibition zone for *E. coli* was 19 mm and for *S. aureus* was 20 mm	[260]
Starch and MgO	• Zone of inhibition was 4–6 mm against *E. coli* and *S. aureus*	[305]
PLA and Ag	• Antimicrobial activity of films observed was 32 and 36 mm for *S. aureus and C. albicans*	[237]
Gelatin/starch and ZnO	• *S. aureus and E. coli*, resulting in 67.28 ± 17 and 85.30 ± 19 mm^2 zones of inhibition, respectively	[306]

6. Future prospects of metal and metal oxide nanoparticles dispersed biofilms

Biopolymeric materials have been extensively used to manufacture various composite products for different environmental applications, such as dye removal [311,312], heavy metals detection and capturing [313–316], and nutrient recovery from wastewater [317–319]. Besides, several studies have been conducted based on using carbohydrate-based polymers in composite film preparation and enhancing their properties. They have provided magnificent results to the research communities in directing the options to extract, utilize, and recover carbohydrate polymers and improving their properties using different techniques. However, the research related to the incorporation of metal nanoparticles for biofilm preparation is yet to be discovered extensively because, for every particular research, there would be a new finding along with enhancing and making better biopolymer-based films. Several cutting-edge research opportunities could be created due to the potential application of metal and metal oxide nanoparticles to develop biofilms commercially. Some of the future prospects of these biofilms include,

- Processing as packaging material with enhanced barrier and anti-microbial properties
- Bringing biobased films to industrial-level processibility and applicability by enhancing their mechanical and thermal properties is essential with novel nanomaterials.
- Many researchers investigated the effect of individual nanoparticles with different carbohydrate polymers. To develop multifunctional biofilms economically and environmentally friendly for various applications, the synergetic impact of different nanomaterials could be performed with different biopolymer sources.
- Controlling the migration and toxicity of nanoparticles in biofilms is to be investigated to design suitable drug-carrying and delivering media, including typical packaging applications.
- Due to the abundance, biodegradability, and biocompatibility of biopolymers, the nanomaterials incorporated biofilms could be a promising option to replace fossil-based polymer products.

7. Conclusions

The effect of petro-based films emerged as a threat to the environment. To solve this emerging effect, biodegradable films have been investigated for their enormous potential to replace petroleum-based polymers. Even though these carbohydrate polymers exhibit good film-forming capacity, they have their limitations. One new trend evolving as the best way to tackle these drawbacks is using metal nanoparticles. The nanoparticles exhibited positive and negative enhancing impacts on the properties of carbohydrate polymers. Nonetheless, it can be concluded that employing various film manufacturing processes and nanoparticles to increase the capabilities of biopolymers is by far the greatest answer to these restrictions. Using NPs as fillers to enhance the properties of biofilms can be seen as a potential factor, yet these NPs also have limitations when dispersed into the films. Resolving the limitation of the NPs and carbohydrate polymers can open up broad future prospects related to biofilms. Thus, this review serves as a good source for producing bio-based films with enhanced properties using metal and metal oxide nanoparticles.

Declaration of competing interest

The authors declare that there is no conflict of interest.

References

[1] K.J. Groh, T. Backhaus, B. Carney-Almroth, B. Geueke, P.A. Inostroza, A. Lennquist, H.A. Leslie, M. Maffini, D. Slunge, L. Trasande, A.M. Warhurst, J. Muncke, Overview of known plastic packaging-associated chemicals and their hazards, Sci. Total Environ. 651 (2019) 3253–3268, https://doi.org/10.1016/j.scitotenv.2018.10.015.
[2] C.L. Luchese, J.M. Frick, V.L. Patzer, J.C. Spada, I.C. Tessaro, Synthesis and characterization of biofilms using native and modified pinhão starch, Food Hydrocoll. 45 (2015) 203–210, https://doi.org/10.1016/j.foodhyd.2014.11.015.
[3] B.A. Mohamed, M. Bilal, E.S. Salama, S. Periyasamy, I.M.R. Fattah, R. Ruan, M. K. Awasthi, L. Leng, Phenolic-rich bio-oil production by microwave catalytic pyrolysis of switchgrass: experimental study, life cycle assessment, and economic analysis, J. Clean. Prod. 366 (2022), 132668, https://doi.org/10.1016/j.jclepro.2022.132668.
[4] B.A. Mohamed, I.M.R. Fattah, B. Yousaf, S. Periyasamy, Effects of the COVID-19 pandemic on the environment, waste management, and energy sectors: a deeper look into the long-term impacts, Environ. Sci. Pollut. Res. 29 (2022) 46438–46457, https://doi.org/10.1007/s11356-022-20259-1.
[5] R. Puscaselu, G. Gutt, S. Amariei, Biopolymer-based films enriched with Stevia rebaudiana used for the development of edible and soluble packaging, Coatings 9 (2019), https://doi.org/10.3390/coatings9060354.

[6] T. Rihayat, Suryani, C.N. Fitriyani, Nurhanifa, J.P. Siregar, J. Jaafar, T. Cionita, Fitria, Synthesis and characterization of PLA-Chitosan-ZnO composite for packaging biofilms, IOP Conf. Ser. Mater. Sci. Eng. 788 (2020), https://doi.org/10.1088/1757-899X/788/1/012045.
[7] I. Hasan, J. Wang, M. Tajvidi, Tuning physical, mechanical and barrier properties of cellulose nanofibril films through film drying techniques coupled with thermal compression, Cellulose. 28 (2021) 11345–11366, https://doi.org/10.1007/s10570-021-04269-9.
[8] M.L. Rathod, A. Shivaputra, H. Umadevi, K. Nagamani, S. Periyasamy, Cloud computing and networking for SmartFarm AgriTech, J. Nanomater. 2022 (2022), https://doi.org/10.1155/2022/6491747.
[9] S. Velusamy, A. Subbaiyan, S.R. Murugesan, M. Shanmugamoorthy, V. Sivakumar, P. Velusamy, S. Veerasamy, K. Mani, P. Sundararaj, S. Periyasamy, Comparative analysis of agro waste material solid biomass briquette for environmental sustainability, Adv. Mater. Sci. Eng. 2022 (2022), https://doi.org/10.1155/2022/3906256.
[10] S. Periyasamy, V. Karthik, P. Senthil Kumar, J.B. Isabel, T. Temesgen, B. M. Hunegnaw, B.B. Melese, B.A. Mohamed, D.V.N. Vo, Chemical, physical and biological methods to convert lignocellulosic waste into value-added products. A review, Environ. Chem. Lett. 20 (2022) 1129–1152, https://doi.org/10.1007/s10311-021-01374-w.
[11] P. Selvakumar, V. Karthik, P.S. Kumar, P. Asaithambi, S. Kavitha, P. Sivashanmugam, Enhancement of ultrasound assisted aqueous extraction of polyphenols from waste fruit peel using dimethyl sulfoxide as surfactant: assessment of kinetic models, Chemosphere 263 (2021), 128071, https://doi.org/10.1016/j.chemosphere.2020.128071.
[12] P. Selvakumar, P. Sivashanmugam, Studies on the extraction of polyphenolic compounds from pre-consumer organic solid waste, J. Ind. Eng. Chem. 82 (2020), https://doi.org/10.1016/j.jiec.2019.10.004.
[13] B. Wang, X. Yang, C. Qiao, Y. Li, T. Li, C. Xu, Effects of chitosan quaternary ammonium salt on the physicochemical properties of sodium carboxymethyl cellulose-based films, Carbohydr. Polym. 184 (2018) 37–46, https://doi.org/10.1016/j.carbpol.2017.12.030.
[14] R. Thakur, P. Pristijono, C.J. Scarlett, M. Bowyer, S.P. Singh, Q.V. Vuong, Starch-based films: major factors affecting their properties, Int. J. Biol. Macromol. 132 (2019) 1079–1089, https://doi.org/10.1016/j.ijbiomac.2019.03.190.
[15] S. Sharma, A. Majumdar, B.S. Butola, Tailoring the biodegradability of polylactic acid (PLA) based films and ramie- PLA green composites by using selective additives, Int. J. Biol. Macromol. 181 (2021) 1092–1103, https://doi.org/10.1016/j.ijbiomac.2021.04.108.
[16] J. Jian, Z. Xiangbin, H. Xianbo, An overview on synthesis, properties and applications of poly(butylene-adipate-co-terephthalate)–PBAT, Adv. Ind. Eng. Polym. Res. 3 (2020) 19–26, https://doi.org/10.1016/j.aiepr.2020.01.001.
[17] H. Haghighi, F. Licciardello, P. Fava, H.W. Siesler, A. Pulvirenti, Recent advances on chitosan-based films for sustainable food packaging applications, Food Packag. Shelf Life 26 (2020), 100551, https://doi.org/10.1016/j.fpsl.2020.100551.
[18] H. Chen, J. Wang, Y. Cheng, C. Wang, H. Liu, H. Bian, Y. Pan, J. Sun, W. Han, Application of protein-based films and coatings for food packaging: a review, Polymers (Basel) 11 (2019) 1–2, https://doi.org/10.3390/polym11122039.
[19] S. Periyasamy, J. Beula Isabel, S. Kavitha, V. Karthik, B.A. Mohamed, D.G. Gizaw, P. Sivashanmugam, T.M. Aminabhavi, Recent advances in consolidated bioprocessing for conversion of lignocellulosic biomass into bioethanol – a review, Chem. Eng. J. 453 (2023), 139783, https://doi.org/10.1016/j.cej.2022.139783.
[20] P. Selvakumar, A.A. Adane, T. Zelalem, B.M. Hunegnaw, V. Karthik, S. Kavitha, M. Jayakumar, N. Karmegam, M. Govarthanan, W. Kim, Optimization of binary acids pretreatment of corncob biomass for enhanced recovery of cellulose to produce bioethanol, Fuel. 321 (2022), 124060, https://doi.org/10.1016/j.fuel.2022.124060.
[21] V. Karthik, P. Senthil Kumar, D.V.N. Vo, P. Selvakumar, M. Gokulakrishnan, P. Keerthana, V. Audilakshmi, J. Jeyanthi, Enzyme-loaded nanoparticles for the degradation of wastewater contaminants: a review, Environ. Chem. Lett. 19 (2021) 2331–2350, https://doi.org/10.1007/s10311-020-01158-8.
[22] D. Domene-López, J.C. García-Quesada, I. Martin-Gullon, M.G. Montalbán, Influence of starch composition and molecular weight on physicochemical properties of biodegradable films, Polymers (Basel) 11 (2019) 1–17, https://doi.org/10.3390/polym11071084.
[23] A.A. Elolimy, J.M. Arroyo, F. Batistel, M.A. Iakiviak, J.J. Loor, Association of residual feed intake with abundance of ruminal bacteria and biopolymer hydrolyzing enzyme activities during the peripartal period and early lactation in Holstein dairy cows, J. Anim. Sci. Biotechnol. 9 (2018) 1–10, https://doi.org/10.1186/s40104-018-0258-9.
[24] T.J. Gutiérrez, J.R. Mendieta, R. Ortega-Toro, In-depth study from gluten/PCL-based food packaging films obtained under reactive extrusion conditions using chrome octanoate as a potential food grade catalyst, Food Hydrocoll. 111 (2021) 1–9, https://doi.org/10.1016/j.foodhyd.2020.106255.
[25] R. Olayil, V. Arumuga Prabu, S. DayaPrasad, K. Naresh, P.S. Rama Sreekanth, A review on the application of bio-nanocomposites for food packaging, Mater. Today Proc. 56 (2022) 1302–1306, https://doi.org/10.1016/j.matpr.2021.11.315.
[26] M. Zhang, X. Shi, X. Dai, C. Huo, J. Xie, X. Li, X. Wang, Improving the crystallization and fire resistance of poly(lactic acid) with nano-ZIF-8@GO, J. Mater. Sci. 53 (2018) 7083–7093, https://doi.org/10.1007/s10853-018-2049-2.
[27] Z. Wu, W. Deng, J. Luo, D. Deng, Multifunctional nano-cellulose composite films with grape seed extracts and immobilized silver nanoparticles, Carbohydr. Polym. 205 (2019) 447–455, https://doi.org/10.1016/j.carbpol.2018.10.060.
[28] R. Priyadarshi, H.J. Kim, J.W. Rhim, Effect of sulfur nanoparticles on properties of alginate-based films for active food packaging applications, Food Hydrocoll. 110 (2021) 1–8, https://doi.org/10.1016/j.foodhyd.2020.106155.
[29] S. Ardebilchi Marand, H. Almasi, N. Ardebilchi Marand, Chitosan-based nanocomposite films incorporated with NiO nanoparticles: physicochemical, photocatalytic and antimicrobial properties, Int. J. Biol. Macromol. 190 (2021) 667–678, https://doi.org/10.1016/j.ijbiomac.2021.09.024.
[30] G. Mamatha, P. Sowmya, D. Madhuri, N. Mohan Babu, D. Suresh Kumar, G. Vijaya Charan, K. Varaprasad, K. Madhukar, Antimicrobial cellulose nanocomposite films with in situ generations of bimetallic (Ag and Cu) nanoparticles using vitex negundo leaves extract, J. Inorg. Organomet. Polym. Mater. 31 (2021) 802–815, https://doi.org/10.1007/s10904-020-01819-9.
[31] A. Muñoz-Bonilla, C. Echeverria, Á. Sonseca, M.P. Arrieta, M. Fernández-García, Bio-based polymers with antimicrobial properties towards sustainable development, Materials (Basel) 12 (2019) 1–2, https://doi.org/10.3390/ma12040641.
[32] A. Nesic, C. Castillo, P. Castaño, G. Cabrera-barjas, J. Serrano, Biobased products and industries chapter 8 - bio-based packaging materials, Biobased Prod. Ind. (2020) 21–23, https://doi.org/10.1016/B978-0-12-818493-6.00008-7.
[33] C. Tan, F. Han, S. Zhang, P. Li, N. Shang, Novel bio-based materials and applications in antimicrobial food packaging: recent advances and future trends, Int. J. Mol. Sci. 22 (2021), https://doi.org/10.3390/ijms22189663.
[34] A. Vinod, M.R. Sanjay, S. Suchart, P. Jyotishkumar, Renewable and sustainable biobased materials: an assessment on biofibers, biofilms, biopolymers and biocomposites, J. Clean. Prod. 258 (2020) 1–7, https://doi.org/10.1016/j.jclepro.2020.120978.
[35] C.M. Ortiz, J.O. de Moraes, A.R. Vicente, J.B. Laurindo, A.N. Mauri, Scale-up of the production of soy (Glycine max L.) protein films using tape casting: formulation of film-forming suspension and drying conditions, Food Hydrocoll. 66 (2017) 110–117, https://doi.org/10.1016/j.foodhyd.2016.12.029.
[36] A. Ferrández-Montero, M. Lieblich, J.L. González-Carrasco, R. Benavente, V. Lorenzo, R. Detsch, A.R. Boccaccini, B. Ferrari, Development of biocompatible and fully bioabsorbable PLA/Mg films for tissue regeneration applications, Acta Biomater. 98 (2019) 114–124, https://doi.org/10.1016/j.actbio.2019.05.026.
[37] Z. Yu, G. Rao, Y. Wei, J. Yu, S. Wu, Y. Fang, Preparation, characterization, and antibacterial properties of biofilms comprising chitosan and ε-polylysine, Int. J. Biol. Macromol. 141 (2019) 545–552, https://doi.org/10.1016/j.ijbiomac.2019.09.035.
[38] D.C. Da Silva, I.A. Lopes, L.J.S. Da Silva, M.F. Lima, A.K.D. Barros Filho, H. A. Villa-Vélez, A.A. Santana, Physical properties of films based on pectin and babassu coconut mesocarp, Int. J. Biol. Macromol. 130 (2019) 419–428, https://doi.org/10.1016/j.ijbiomac.2019.02.151.
[39] O.M. Atta, S. Manan, A.A.Q. Ahmed, M.F. Awad, M. Ul-Islam, F. Subhan, M. W. Ullah, G. Yang, Development and characterization of yeast-incorporated antimicrobial cellulose biofilms for edible food packaging application, Polymers (Basel) 13 (2021), https://doi.org/10.3390/polym13142310.
[40] C. Zhang, H. Sun, Q. Zhu, Study on flexible large-area poly(vinylidene fluoride)-based piezoelectric films prepared by extrusion-casting process for sensors and microactuators, Mater. Chem. Phys. 275 (2022) 21–23, https://doi.org/10.1016/j.matchemphys.2021.125221.
[41] W. Wang, H. Zhang, R. Jia, Y. Dai, H. Dong, H. Hou, Q. Guo, High performance extrusion blown starch/polyvinyl alcohol/clay nanocomposite films, Food Hydrocoll. 79 (2018) 534–543, https://doi.org/10.1016/j.foodhyd.2017.12.013.
[42] D.E. Rodr, J. Romero-garc, D. Cabrera-germ, C. Nacional, A. Number, Extrusion of polypropylene/chitosan/poly(lactic-acid) ?lms: chemical, mechanical, and thermal properties, J. Appl. Polym. Sci. 138 (2021) 1–2, https://doi.org/10.1002/app.49850.
[43] C. Li, Y. Li, C. Gong, K. Ruan, X. Zhong, P. Pan, C. Liu, J. Gu, X. Shi, High thermal conductivity of liquid crystalline monomer-poly (vinyl alcohol) dispersion films containing microscopic-ordered structure, J. Appl. Polym. Sci. 138 (2021) 1–11, https://doi.org/10.1002/app.49791.
[44] P. Guerrero, A. Muxika, I. Zarandona, K. de la Caba, Crosslinking of chitosan films processed by compression molding, Carbohydr. Polym. 206 (2019) 820–826, https://doi.org/10.1016/j.carbpol.2018.11.064.
[45] T. Garrido, A. Etxabide, P. Guerrero, K. De La Caba, Characterization of agar/soy protein biocomposite films: effect of agar on the extruded pellets and compression moulded films, Carbohydr. Polym. 151 (2016) 408–416, https://doi.org/10.1016/j.carbpol.2016.05.089.
[46] X. He, W. Lu, C. Sun, H. Khalesi, A. Mata, R. Andaleeb, Y. Fang, Cellulose and cellulose derivatives: different colloidal states and food-related applications, Carbohydr. Polym. 255 (2021) 2021–2023, https://doi.org/10.1016/j.carbpol.2020.117334.
[47] R. Zhang, X. Wang, M. Cheng, Preparation and characterization of potato starch film with various size of Nano-SiO2, Polymers (Basel) 10 (2018) 1–2, https://doi.org/10.3390/POLYM10101172.
[48] H. Zhu, W. Luo, P.N. Ciesielski, Z. Fang, J.Y. Zhu, G. Henriksson, M.E. Himmel, L. Hu, Wood-derived materials for green electronics, biological devices, and energy applications, Chem. Rev. 116 (2016) 9305–9374, https://doi.org/10.1021/acs.chemrev.6b00225.
[49] S.-W. Zhao, C.-R. Guo, Y.-Z. Hu, Y.-R. Guo, Q.-J. Pan, The preparation and antibacterial activity of cellulose/ZnO composite: a review, De Gruyter 16 (2018) 9–20, https://doi.org/10.1515/chem-2018-0006.

[50] S. Wu, D. Ning, D. Xu, Y. Cheng, A.K. Mondal, Q. Zou, H. Zhu, F. Huang, Preparation and characterization of super hydrophobic aerogels derived from tunicate cellulose nanocrystals, Carbohydr. Res. 511 (2022) 21–24, https://doi.org/10.1016/j.carres.2021.108488.
[51] H. Khan, A. Kadam, D. Dutt, Studies on bacterial cellulose produced by a novel strain of Lactobacillus genus, Carbohydr. Polym. 229 (2020) 31826477, https://doi.org/10.1016/j.carbpol.2019.115513.
[52] S. Zarei, M. Niad, H. Raanaei, The removal of mercury ion pollution by using Fe3O4-nanocellulose: synthesis, characterizations and DFT studies, J. Hazard. Mater. 344 (2018) 258–273, https://doi.org/10.1016/j.jhazmat.2017.10.009.
[53] B.T. Nguyen Thi, L.K. Ong, D.T. Nguyen Thi, Y.H. Ju, Effect of subcritical water pretreatment on cellulose recovery of water hyacinth (Eichhornia crassipe), J. Taiwan Inst. Chem. Eng. 71 (2017) 55–61, https://doi.org/10.1016/j.jtice.2016.12.028.
[54] S. Palamae, P. Dechatiwongse, W. Choorit, Y. Chisti, P. Prasertsan, Cellulose and hemicellulose recovery from oil palm empty fruit bunch (EFB) fibers and production of sugars from the fibers, Carbohydr. Polym. 155 (2017) 491–497, https://doi.org/10.1016/j.carbpol.2016.09.004.
[55] A. Fadakar Sarkandi, M. Montazer, T. Harifi, M. Mahmoudi Rad, Innovative preparation of bacterial cellulose/silver nanocomposite hydrogels: in situ green synthesis, characterization, and antibacterial properties, J. Appl. Polym. Sci. 138 (2021) 1–12, https://doi.org/10.1002/app.49824.
[56] K. Mondal, S. Sakurai, Y. Okahisa, V.V. Goud, V. Katiyar, Effect of cellulose nanocrystals derived from Dunaliella tertiolecta marine green algae residue on crystallization behaviour of poly(lactic acid), Carbohydr. Polym. 261 (2021) 2021–2024, https://doi.org/10.1016/j.carbpol.2021.117881.
[57] J. Gong, J. Li, J. Xu, Z. Xiang, L. Mo, Research on cellulose nanocrystals produced from cellulose sources with various polymorphs, RSC Adv. 7 (2017) 33486–33493, https://doi.org/10.1039/c7ra06222b.
[58] M. Nuruddin, R.A. Chowdhury, R. Szeto, J.A. Howarter, K.A. Erk, C. R. Szczepanski, J.P. Youngblood, Structure-property relationship of cellulose nanocrystal-polyvinyl alcohol thin films for high barrier coating applications, ACS Appl. Mater. Interfaces 13 (2021) 12472–12482, https://doi.org/10.1021/acsami.0c21525.
[59] O.M. Atta, S. Manan, M. Ul-Islam, A.A.Q. Ahmed, M.W. Ullah, G. Yang, Silver decorated bacterial cellulose nanocomposites as antimicrobial food packaging materials, ES Food Agrofor. 6 (2021) 12–26, https://doi.org/10.30919/esfaf590.
[60] M. Reimer, C. Zollfrank, Cellulose for light manipulation: methods, applications, and prospects, Adv. Energy Mater. 11 (2021), https://doi.org/10.1002/aenm.202003866.
[61] C. Shi, L. Zhang, H. Bian, Z. Shi, J. Ma, Z. Wang, Construction of Ag–ZnO/cellulose nanocomposites via tunable cellulose size for improving photocatalytic performance, J. Clean. Prod. 288 (2021) 1–8, https://doi.org/10.1016/j.jclepro.2020.125089.
[62] C. Krumm, J. Pfaendtner, P.J. Dauenhauer, Millisecond pulsed films unify the mechanisms of cellulose fragmentation, Chem. Mater. 28 (2016) 3108–3114, https://doi.org/10.1021/acs.chemmater.6b00580.
[63] X. Wang, Y. Tang, X. Zhu, Y. Zhou, X. Hong, Preparation and characterization of polylactic acid/polyaniline/nanocrystalline cellulose nanocomposite films, Int. J. Biol. Macromol. 146 (2020) 1069–1075, https://doi.org/10.1016/j.ijbiomac.2019.09.233.
[64] X. Wang, L. Cui, S. Fan, X. Li, Y. Liu, Biodegradable poly(butylene adipate-co-terephthalate) antibacterial nanocomposites reinforced with MgO nanoparticles, Polymers (Basel). 13 (2021) 1–11, https://doi.org/10.3390/polym13040507.
[65] S. Punia Bangar, M. Nehra, A.K. Siroha, M. Petrů, R.A. Ilyas, U. Devi, P. Devi, Development and characterization of physical modified pearl millet starch-based films, Foods. 10 (2021), https://doi.org/10.3390/foods10071609.
[66] B.I.O. Ade-Omowaye, I. Smetanska, D. Mamdouh, Potential industrial applications of bambara groundnut, in: Food Potential Ind. Appl. Bambara Groundn, 2021, pp. 209–226, https://doi.org/10.1007/978-3-030-73920-1_12.
[67] M.D. Eaton, D. Domene-López, Q. Wang, M.G. Montalbán, I. Martin-Gullon, K. R. Shull, Exploring the effect of humidity on thermoplastic starch films using the quartz crystal microbalance, Carbohydr. Polym. 261 (2021) 2021–2024, https://doi.org/10.1016/j.carbpol.2021.117727.
[68] S.P. Bangar, M. Kumar, W.S. Whiteside, Mango seed starch: a sustainable and eco-friendly alternative to increasing industrial requirements, Int. J. Biol. Macromol. 183 (2021) 2021–2023, https://doi.org/10.1016/j.ijbiomac.2021.05.157.
[69] C. Cui, N. Ji, Y. Wang, L. Xiong, Q. Sun, Trends in Food Science & Technology Bioactive and intelligent starch-based films: a review, Trends Food Sci. Technol. 116 (2021) 854–869, https://doi.org/10.1016/j.tifs.2021.08.024.
[70] S. Ochoa, M.M. Durango-Zuleta, J.F. Osorio-Tobón, Integrated process for obtaining anthocyanins rich-extract by ultrasound-assisted extraction and starch recovery from purple yam (Dioscorea alata): a techno-economic evaluation, Biomass Convers. Biorefin. (2021) 1–14, https://doi.org/10.1007/s13399-021-01935-7.
[71] Á.L. Santana, G.L. Zabot, J.F. Osorio-Tobón, J.C.F. Johner, A.S. Coelho, M. Schmiele, C.J. Steel, M.A.A. Meireles, Starch recovery from turmeric wastes using supercritical technology, J. Food Eng. 214 (2017) 266–276, https://doi.org/10.1016/j.jfoodeng.2017.07.010.
[72] M.D. Torres, P. Fradinho, P. Rodríguez, E. Falqué, V. Santos, H. Domínguez, Biorefinery concept for discarded potatoes: recovery of starch and bioactive compounds, J. Food Eng. 275 (2020) 1–8, https://doi.org/10.1016/j.jfoodeng.2019.109886.
[73] J. Ballester-Sánchez, J.V. Gil, M.T. Fernández-Espinar, C.M. Haros, Quinoa wet-milling: effect of steeping conditions on starch recovery and quality, Food Hydrocoll. 89 (2019) 837–843, https://doi.org/10.1016/j.foodhyd.2018.11.053.
[74] Y. Zhuang, S. Ruan, H. Yao, Y. Sun, Physical properties of composite films from tilapia skin collagen with Pachyrhizus starch and rambutan peel phenolics, Mar. Drugs. 17 (2019) 1–2, https://doi.org/10.3390/md17120662.
[75] C.N. Bernardo, I.C.S. Kling, W.H. Ferreira, C.T. Andrade, R.A. Simao, Starch films containing starch nanoparticles as produced in a single step green route, Ind. Crop. Prod. 177 (2022) 1–8, https://doi.org/10.1016/j.indcrop.2021.114481.
[76] S.H. Othman, N.A. Majid, I. Syafinaz, M. Amin, R.K. Basha, N. Nordin, R.A.S. I, Tapioca starch films reinforced with microcrystalline cellulose for potential food packaging application, Food Sci. Technol. 2061 (2019) 605–612, https://doi.org/10.1590/fst.36017.
[77] M.S. Mohseni, M.A. Khalilzadeh, M. Mohseni, F.Z. Hargalani, M.I. Getso, V. Raissi, O. Raiesi, Green synthesis of Ag nanoparticles from pomegranate seeds extract and synthesis of Ag-starch nanocomposite and characterization of mechanical properties of the films, Biocatal. Agric. Biotechnol. 25 (2020) 1–9, https://doi.org/10.1016/j.bcab.2020.101569.
[78] M. Ghozali, W.K. Restu, E. Triwulandari, M. Anwar, Effect of metal oxide as antibacterial agent on thermoplastic starch/metal oxide biocomposites properties, Polym. Technol. Mater. 59 (2020) 1317–1325, https://doi.org/10.1080/25740881.2020.1738473.
[79] X. Hu, X. Jia, C. Zhi, Z. Jin, M. Miao, Improving the properties of starch-based antimicrobial composite films using ZnO-chitosan nanoparticles, Carbohydr. Polym. 210 (2019) 204–209, https://doi.org/10.1016/j.carbpol.2019.01.043.
[80] Q. Chen, H. Yu, L. Wang, Z. Ul Abdin, Y. Chen, J. Wang, W. Zhou, X. Yang, R. U. Khan, H. Zhang, X. Chen, Recent progress in chemical modification of starch and its applications, RSC Adv. 5 (2015) 67459–67474, https://doi.org/10.1039/c5ra10849g.
[81] D. Qiao, S. Li, L. Yu, B. Zhang, G. Simon, F. Jiang, Effect of alkanol surface grafting on the hydrophobicity of starch-based films, Int. J. Biol. Macromol. 112 (2018) 761–766.
[82] J.C. Cazotti, A.T. Fritz, O. Garcia-Valdez, N.M.B. Smeets, M.A. Dubé, M. F. Cunningham, Grafting from starch nanoparticles with synthetic polymers via nitroxide-mediated polymerization, Macromol. Rapid Commun. 40 (2019) 1800834.
[83] P. Nallasamy, T. Ramalingam, T. Nooruddin, R. Shanmuganathan, P. Arivalagan, S. Natarajan, Polyherbal drug loaded starch nanoparticles as promising drug delivery system: antimicrobial, antibiofilm and neuroprotective studies, Process Biochem. 92 (2020) 355–364.
[84] D. Sondari, Modification of sago starch for edible coating, in: IOP Conf. Ser. Mater. Sci. Eng, IOP Publishing, 2019, p. 12013.
[85] S. Chakrabarti, S. Guha, K. Majumder, Food-derived bioactive peptides in human health: challenges and opportunities, Nutrients 10 (2018) 1–2, https://doi.org/10.3390/nu10111738.
[86] E.M. Herz, S. Schäfer, N. Terjung, M. Gibis, J. Weiss, Influence of transglutaminase on glucono-δ-lactone-induced soy protein gels, ACS Food Sci. Technol. 1 (2021) 1412–1417, https://doi.org/10.1021/acsfoodscitech.1c00102.
[87] N. Karimi, A. Alizadeh, H. Almasi, S. Hanifian, Preparation and characterization of whey protein isolate/polydextrose-based nanocomposite film incorporated with cellulose nanofiber and L. plantarum: a new probiotic active packaging system, Food Sci. Technol. 121 (2020) 1–5, https://doi.org/10.1016/j.lwt.2019.108978.
[88] X. Tong, J. Cao, T. Tian, B. Lyu, L. Miao, Z. Lian, W. Cui, S. Liu, H. Wang, L. Jiang, Changes in structure, rheological property and antioxidant activity of soy protein isolate fibrils by ultrasound pretreatment and EGCG, Food Hydrocoll. 122 (2022) 1–8, https://doi.org/10.1016/j.foodhyd.2021.107084.
[89] H.W. Lee, Y. Lu, Y. Zhang, C. Fu, D. Huang, Physicochemical and functional properties of red lentil protein isolates from three origins at different pH, Food Chem. 358 (2021) 2021–2023, https://doi.org/10.1016/j.foodchem.2021.129749.
[90] A. Tamayo Tenorio, J. Gieteling, G.A.H. De Jong, R.M. Boom, A.J. Van Der Goot, Recovery of protein from green leaves: overview of crucial steps for utilisation, Food Chem. 203 (2016) 402–408, https://doi.org/10.1016/j.foodchem.2016.02.092.
[91] R. la Cour, J.K. Schjoerring, H. Jørgensen, Enhancing protein recovery in green biorefineries by lignosulfonate-assisted precipitation, Front. Sustain. Food Syst. 3 (2019) 1–9, https://doi.org/10.3389/fsufs.2019.00112.
[92] L.M. Greenfield, Soil proteases: widening the bottleneck of the terrestrial nitrogen cycle, Encycl. Ecol. (2021) 135–142, https://doi.org/10.1016/B978-0-12-409548-9.00944-1.
[93] A. Sarker, A.S. Rathore, R.D. Gupta, Evaluation of scFv protein recovery from E. coli by in vitro refolding and mild solubilization process, Microb. Cell Factories 18 (2019) 1–12, https://doi.org/10.1186/s12934-019-1053-9.
[94] A. Insaward, K. Duangmal, T. Mahawanich, Mechanical, optical, and barrier properties of soy protein film as affected by phenolic acid addition, J. Agric. Food Chem. 63 (2015) 9421–9426, https://doi.org/10.1021/jf504016m.
[95] V.M. Azevedo, R.A. Carvalho, S.V. Borges, P.I.C. Claro, F.K. Hasegawa, M. I. Yoshida, J.M. Marconcini, Thermoplastic starch/whey protein isolate/rosemary essential oil nanocomposites obtained by extrusion process: antioxidant polymers, J. Appl. Polym. Sci. 136 (2019) 1–12, https://doi.org/10.1002/app.47619.
[96] N. Fathi, H. Almasi, M.K. Pirouzifard, Effect of ultraviolet radiation on morphological and physicochemical properties of sesame protein isolate based edible films, Food Hydrocoll. 85 (2018) 136–143, https://doi.org/10.1016/j.foodhyd.2018.07.018.
[97] V. Mihalca, A.D. Kerezsi, A. Weber, C. Gruber-traub, J. Schmucker, F. Anca, D. C. Vodnar, F.V. Dulf, S. Ancut, R. Suharoschi, O.L. Pop, Protein-based films and

coatings for food industry applications, Polymers (Basel). 13 (2021) 1–23, https://doi.org/10.3390/polym13050769.
[98] S. Vinayashree, P. Vasu, Biochemical, nutritional and functional properties of protein isolate and fractions from pumpkin (Cucurbita moschata var. Kashi Harit) seeds, Food Chem. 340 (2021) 2021–2024, https://doi.org/10.1016/j.foodchem.2020.128177.
[99] C. Fan, H. Chi, C. Zhang, R. Cui, W. Lu, M. Yuan, Y. Qin, Effect of multiscale structure on the gas barrier properties of poly(lactic acid)/Ag nanocomposite films, Polym. Adv. Technol. 30 (2019) 1709–1715, https://doi.org/10.1002/pat.4601.
[100] M. Yang, L. Wang, Y. Xia, Ammonium persulphate induced synthesis of polymethyl methacrylate grafted sodium alginate composite films with high strength for food packaging, Int. J. Biol. Macromol. 124 (2019) 1238–1245.
[101] S. Dong, X. Li, P. Guo, Y. Chen, H. Li, Preparation and characterization of PCL-grafted zein film via atmospheric-pressure cold plasma pretreatment, Plasma Process. Polym. 18 (2021) 2000242.
[102] M.F. Di Filippo, S. Panzavolta, B. Albertini, F. Bonvicini, G.A. Gentilomi, R. Orlacchio, N. Passerini, A. Bigi, L.S. Dolci, Functional Properties of Chitosan Films Modified by Snail Mucus Extract, Elsevier B.V, 2020, https://doi.org/10.1016/j.ijbiomac.2019.11.230.
[103] J.M. Moura, B.S. Farias, T.R.S. Cadaval, L.A.A. Pinto, Chitin/chitosan based films for packaging applications, in: Biobased Packag. Environ. Econ. Asp, 2021, pp. 69–83.
[104] P. Zimet, Á.W. Mombrú, D. Mombrú, A. Castro, J.P. Villanueva, H. Pardo, C. Rufo, Physico-chemical and antilisterial properties of nisin-incorporated chitosan/carboxymethyl chitosan films, Carbohydr. Polym. 219 (2019) 334–343, https://doi.org/10.1016/j.carbpol.2019.05.013.
[105] S. Mane, E. Pathan, S. Tupe, S. Deshmukh, D. Kale, V. Ghormade, B. Chaudhari, M. Deshpande, Isolation and characterization of chitosans from different fungi with special emphasis on zygomycetous dimorphic fungus Benjaminiella poitrasii: evaluation of its chitosan nanoparticles for the inhibition of human pathogenic fungi, Biomacromolecules 23 (2022) 808–815, https://doi.org/10.1021/acs.biomac.1c01248.
[106] A. Khayrova, S. Lopatin, B. Shagdarova, O. Sinitsyna, A. Sinitsyn, V. Varlamov, Evaluation of antibacterial and antifungal properties of low molecular weight chitosan extracted from hermetia illucens relative to crab chitosan, Molecules 27 (2022), https://doi.org/10.3390/molecules27020577.
[107] X. Liu, Y. Zhang, Y. Liu, T. Zhang, Green method to synthesize magnetic zeolite/chitosan composites and adsorption of hexavalent chromium from aqueous solutions, Int. J. Biol. Macromol. 194 (2022) 746–754, https://doi.org/10.1016/j.ijbiomac.2021.11.121.
[108] J. Gopal, M. Muthu, T. Dhakshanamurthy, K.J. Kim, N. Hasan, S.J. Kwon, S. Chun, Sustainable ecofriendly phytoextract mediated one pot green recovery of chitosan, Sci. Rep. 9 (2019) 1–12, https://doi.org/10.1038/s41598-019-50133-z.
[109] T.S. Trung, L.H. Tram, N. Van Tan, N. Van Hoa, N.C. Minh, P.T. Loc, W.F. Stevens, Improved method for production of chitin and chitosan from shrimp shells, Carbohydr. Res. 489 (2020) 2020–2023, https://doi.org/10.1016/j.carres.2020.107913.
[110] M. Muthu, J. Gopal, S. Chun, A.J.P. Devadoss, N. Hasan, I. Sivanesan, Crustacean waste-derived chitosan: Antioxidant properties and future perspective, Antioxidants 10 (2021) 1–27, https://doi.org/10.3390/antiox10020228.
[111] S.A. Doğdu, C. Turan, T. Depci, Extraction and characterization of chitin and chitosan from invasive alien swimming crab Charybdis longicollis, Nat. Eng. Sci. 6 (2021) 96–101, https://doi.org/10.28978/nesciences.970546.
[112] A.O. Olaosebikan, O.A. Kehinde, O.A. Tolulase, E.B. Victor, Extraction and characterization of chitin and chitosan from Callinectes amnicola and Penaeus notialis shell wastes, J. Chem. Eng. Mater. Sci. 12 (2021) 1–30, https://doi.org/10.5897/jcems2020.0353.
[113] Y. Liu, Y. Yuan, S. Duan, C. Li, B. Hu, A. Liu, D. Wu, H. Cui, L. Lin, J. He, W. Wu, Preparation and characterization of chitosan films with three kinds of molecular weight for food packaging, Int. J. Biol. Macromol. 155 (2020) 249–259, https://doi.org/10.1016/j.ijbiomac.2020.03.217.
[114] M.E. Abd El-Hack, M.T. El-Saadony, M.E. Shafi, N.M. Zabermawi, M. Arif, G. E. Batiha, A.F. Khafaga, Y.M. Abd El-Hakim, A.A. Al-Sagheer, Antimicrobial and antioxidant properties of chitosan and its derivatives and their applications: A review, Int. J. Biol. Macromol. 164 (2020) 2726–2744, https://doi.org/10.1016/j.ijbiomac.2020.08.153.
[115] T.G. Ambaye, M. Vaccari, S. Prasad, E.D. van Hullebusch, S. Rtimi, Preparation and applications of chitosan and cellulose composite materials, J. Environ. Manag. 301 (2022) 21–24, https://doi.org/10.1016/j.jenvman.2021.113850.
[116] A.A. Kadam, S. Singh, K.K. Gaikwad, Chitosan based antioxidant films incorporated with pine needles (Cedrus deodara) extract for active food packaging applications, Food Control 124 (2021) 1–8, https://doi.org/10.1016/j.foodcont.2021.107877.
[117] A.E. Caprifico, E. Polycarpou, P.J.S. Foot, G. Calabrese, Biomedical and Pharmacological Uses of Fluorescein Isothiocyanate Chitosan-Based Nanocarriers, Macromol. Biosci. 21 (2021) 33016007, https://doi.org/10.1002/mabi.202000312.
[118] F.S. Rezaei, F. Sharifianjazi, A. Esmaeilkhanian, E. Salehi, Chitosan films and scaffolds for regenerative medicine applications: a review, Carbohydr. Polym. 273 (2021) 21–24, https://doi.org/10.1016/j.carbpol.2021.118631.
[119] Y. Ni, H. Nie, J. Wang, J. Lin, Q. Wang, J. Sun, W. Zhang, J. Wang, Enhanced functional properties of chitosan films incorporated with curcumin-loaded hollow graphitic carbon nitride nanoparticles for bananas preservation, Food Chem. 366 (2022) 2022–2024, https://doi.org/10.1016/j.foodchem.2021.130539.
[120] Y. Yuan, X. Zhang, Z. Pan, Q. Xue, Y. Wu, Y. Li, B. Li, L. Li, Improving the properties of chitosan films by incorporating shellac nanoparticles, Food Hydrocoll. 110 (2021) 1–8, https://doi.org/10.1016/j.foodhyd.2020.106164.
[121] A.S. Konda, Effect of Aluminum Oxide on the Functional Properties of Chitosan Films, 2021.
[122] A.G. Niculescu, A.M. Grumezescu, Applications of chitosan-alginate-based nanoparticles— an up-to-date review, Nanomaterials. 12 (2022), https://doi.org/10.3390/nano12020186.
[123] F. Yu, X. Fei, Y. He, H. Li, Poly(lactic acid)-based composite film reinforced with acetylated cellulose nanocrystals and ZnO nanoparticles for active food packaging, Int. J. Biol. Macromol. 186 (2021) 770–779, https://doi.org/10.1016/j.ijbiomac.2021.07.097.
[124] H. Yong, Y. Liu, D. Yun, S. Zong, C. Jin, J. Liu, Chitosan films functionalized with different hydroxycinnamic acids: Preparation, characterization and application for pork preservation, Foods. 10 (2021) 536.
[125] L. Liu, Y. Xu, Y. Pan, M. Xu, Y. Di, B. Li, Facile synthesis of an efficient phosphonamide flame retardant for simultaneous enhancement of fire safety and crystallization rate of poly (lactic acid), Chem. Eng. J. 421 (2021) 1–9, https://doi.org/10.1016/j.cej.2020.127761.
[126] K. Wegrzynowska-Drzymalska, P. Grebicka, D.T. Mlynarczyk, D. Chelminiak-Dudkiewicz, H. Kaczmarek, T. Goslinski, M. Ziegler-Borowska, Crosslinking of chitosan with dialdehyde chitosan as a new approach for biomedical applications, Materials (Basel). 13 (2020) 3413.
[127] J. Khouri, A. Penlidis, C. Moresoli, Viscoelastic properties of crosslinked chitosan films, Processes. 7 (2019) 157.
[128] W. Yang, Y. Weng, D. Puglia, G. Qi, W. Dong, J.M. Kenny, P. Ma, Poly(lactic acid)/lignin films with enhanced toughness and anti-oxidation performance for active food packaging, Int. J. Biol. Macromol. 144 (2020) 102–110, https://doi.org/10.1016/j.ijbiomac.2019.12.085.
[129] M. Nofar, D. Sacligil, P.J. Carreau, M.R. Kamal, M.C. Heuzey, Poly (lactic acid) blends: processing, properties and applications, Int. J. Biol. Macromol. 125 (2019) 307–360, https://doi.org/10.1016/j.ijbiomac.2018.12.002.
[130] S. Asadi, S. Pirsa, Production of biodegradable film based on polylactic acid, modified with lycopene pigment and TiO2 and studying its physicochemical properties, J. Polym. Environ. 28 (2020) 433–444, https://doi.org/10.1007/s10924-019-01618-5.
[131] B. Bindhu, R. Renisha, L. Roberts, T.O. Varghese, Boron Nitride reinforced polylactic acid composites film for packaging: preparation and properties, Polym. Test. 66 (2018) 172–177, https://doi.org/10.1016/j.polymertesting.2018.01.018.
[132] S.K. Dogan, S. Boyacioglu, M. Kodal, O. Gokce, G. Ozkoc, Thermally induced shape memory behavior, enzymatic degradation and biocompatibility of PLA/TPU blends: "effects of compatibilization", J. Mech. Behav. Biomed. Mater. 71 (2017) 349–361, https://doi.org/10.1016/j.jmbbm.2017.04.001.
[133] N. Mallegni, T.V. Phuong, M.B. Coltelli, P. Cinelli, A. Lazzeri, Poly(lactic acid) (PLA) based tear resistant and biodegradable flexible films by blown film extrusion, Materials (Basel) 11 (2018), https://doi.org/10.3390/ma11010148.
[134] R.D. Kale, V.G. Gorade, N. Madye, B. Chaudhary, P.S. Bangde, P.P. Dandekar, Preparation and characterization of biocomposite packaging film from poly(lactic acid) and acylated microcrystalline cellulose using rice bran oil, Int. J. Biol. Macromol. 118 (2018) 1090–1102, https://doi.org/10.1016/j.ijbiomac.2018.06.076.
[135] N. Ciarfaglia, A. Laezza, L. Lods, A. Lonjon, J. Dandurand, A. Pepe, B. Bochicchio, Thermal and dynamic mechanical behavior of poly(lactic acid) (PLA)-based electrospun scaffolds for tissue engineering, J. Appl. Polym. Sci. 138 (2021) 1–11, https://doi.org/10.1002/app.51313.
[136] J. Andrzejewski, Development of toughened flax fiber reinforced composites. Modification of poly(lactic acid)/poly(butylene), Materials (Basel). 14 (2021) 153, https://doi.org/10.3390/ma14061523.
[137] M. Bednarek, K. Borska, P. Kubisa, New polylactide-based materials by chemical crosslinking of PLA, Polym. Rev. 61 (2021) 493–519, https://doi.org/10.1080/15583724.2020.1855194.
[138] A.A. Omar, M.H.M. Hanafi, N.H. Razak, A. Ibrahim, N.A.A. Razak, A best-evidence review of bio-based plasticizer and the effects on the mechanical properties of PLA, Chem. Eng. Trans. 89 (2021) 241–246, https://doi.org/10.3303/CET2189041.
[139] T.F. Nelson, S.C. Remke, H.P.E. Kohler, K. McNeill, M. Sander, Quantification of synthetic polyesters from biodegradable mulch films in soils, Environ. Sci. Technol. (2019), https://doi.org/10.1021/acs.est.9b05863.
[140] M. Seray, A. Skender, A.S. Hadj-Hamou, Kinetics and mechanisms of Zn2+ release from antimicrobial food packaging based on poly (butylene adipate-co-terephthalate) and zinc oxide nanoparticles, Polym. Bull. 78 (2021) 1021–1040, https://doi.org/10.1007/s00289-020-03145-z.
[141] A. Kanwal, M. Zhang, F. Sharaf, C. Li, Polymer pollution and its solutions with special emphasis on Poly (butylene adipate terephthalate (PBAT)), Polym. Bull. 79 (2022) 9303–9330, https://doi.org/10.1007/s00289-021-04065-2.
[142] J. Shen, K. Wang, Z. Ma, N. Xu, S. Pang, L. Pan, Biodegradable blends of poly (butylene adipate-co-terephthalate) and polyglycolic acid with enhanced mechanical, rheological and barrier performances, J. Appl. Polym. Sci. 138 (2021) 1–15, https://doi.org/10.1002/app.51285.
[143] Q. Xing, P. Buono, D. Ruch, P. Dubois, L. Wu, W.J. Wang, Biodegradable UV-blocking films through core-shell lignin-melanin nanoparticles in poly(butylene adipate- co-terephthalate), ACS Sustain. Chem. Eng. 7 (2019) 4147–4157, https://doi.org/10.1021/acssuschemeng.8b05755.

[144] J.M. Farias da Silva, B.G. Soares, Epoxidized cardanol-based prepolymer as promising biobased compatibilizing agent for PLA/PBAT blends, Polym. Test. 93 (2021), 106889, https://doi.org/10.1016/j.polymertesting.2020.106889.
[145] W. Chen, C. Qi, Y. Li, H. Tao, The degradation investigation of biodegradable PLA/PBAT blend: thermal stability, mechanical properties and PALS analysis, Radiat. Phys. Chem. 180 (2021), 109239.
[146] X. Zhai, W. Wang, H. Zhang, Y. Dai, H. Dong, H. Hou, Effects of high starch content on the physicochemical properties of starch/PBAT nanocomposite films prepared by extrusion blowing, Carbohydr. Polym. 239 (2020) 2020–2023, https://doi.org/10.1016/j.carbpol.2020.116231.
[147] L. García-Guzmán, G. Cabrera-Barjas, C.G. Soria-Hernández, J. Castaño, A. Y. Guadarrama-Lezama, S. Rodríguez Llamazares, Progress in starch-based materials for food packaging applications, Polysaccharides 3 (2022) 136–177, https://doi.org/10.3390/polysaccharides3010007.
[148] G. Bheemaneni, S. Saravana, R. Kandaswamy, Processing and characterization of poly (butylene adipate-co-terephthalate)/wollastonite biocomposites for medical applications, Mater. Today Proc. 5 (2018) 1807–1816, https://doi.org/10.1016/j.matpr.2017.11.279.
[149] G.A.M. Falcão, T.G. Almeida, M.A.G. Bardi, L.H. Carvalho, E.L. Canedo, PBAT/organoclay composite films—part 2: effect of UV aging on permeability, mechanical properties and biodegradation, Polym. Bull. 76 (2019) 291–301, https://doi.org/10.1007/s00289-018-2385-z.
[150] S. Qiu, Y. Zhou, G.I.N. Waterhouse, R. Gong, J. Xie, K. Zhang, J. Xu, Optimizing interfacial adhesion in PBAT/PLA nanocomposite for biodegradable packaging films, Food Chem. 334 (2021) 2021–2023, https://doi.org/10.1016/j.foodchem.2020.127487.
[151] C. Zhang, F. Chen, W. Meng, C. Li, R. Cui, Z. Xia, C. Liu, Polyurethane prepolymer-modified high-content starch-PBAT films, Carbohydr. Polym. 253 (2021), 117168.
[152] P. Pleva, L. Bartošová, D. Mǎcalová, L. Zálešáková, J. Sedlaříková, M. Janalíková, Biofilm formation reduction by eugenol and thymol on biodegradable food packaging material, Foods 11 (2022) 1–14, https://doi.org/10.3390/foods11010002.
[153] M. Szymanska-Chargot, M. Chylinska, K. Gdula, A. Koziol, A. Zdunek, Isolation and characterization of cellulose from different fruit and vegetable pomaces, Polymers (Basel). 9 (2017), https://doi.org/10.3390/polym9100495.
[154] M.H. Salim, Z. Kassab, E. Houssaine Ablouh, H. Sehaqui, A. Aboulkas, R. Bouhfid, A.E.K. Qaiss, M. El Achaby, Manufacturing of macroporous cellulose monolith from green macroalgae and its application for wastewater treatment, Int. J. Biol. Macromol. 200 (2022) 182–192, https://doi.org/10.1016/j.ijbiomac.2021.12.153.
[155] Z. Kassab, I. Kassem, H. Hannache, R. Bouhfid, A.E.K. Qaiss, M. El Achaby, Tomato plant residue as new renewable source for cellulose production: extraction of cellulose nanocrystals with different surface functionalities, Cellulose 27 (2020) 4287–4303, https://doi.org/10.1007/s10570-020-03097-7.
[156] J. Ye, S. Zheng, Z. Zhang, F. Yang, K. Ma, Y. Feng, J. Zheng, D. Mao, X. Yang, Bacterial cellulose production by Acetobacter xylinum ATCC 23767 using tobacco waste extract as culture medium, Bioresour. Technol. 274 (2019) 518–524, https://doi.org/10.1016/j.biortech.2018.12.028.
[157] M. Ghozali, Y. Meliana, M. Chalid, Synthesis and characterization of bacterial cellulose by Acetobacter xylinum using liquid tapioca waste, Mater. Today Proc. 44 (2021) 2131–2134, https://doi.org/10.1016/j.matpr.2020.12.274.
[158] Z. Cheng, R. Yang, X. Liu, Production of bacterial cellulose by Acetobacter xylinum through utilizing acetic acid hydrolysate of bagasse as low-cost carbon source, J. Chin. Pharm. Sci. 26 (2016) 1190–1200, https://doi.org/10.15376/biores.12.1.1190-1200.
[159] V. Jonjaroen, S. Ummartyotin, S. Chittapun, Algal cellulose as a reinforcement in rigid polyurethane foam, Algal Res. 51 (2020) 1–9, https://doi.org/10.1016/j.algal.2020.102057.
[160] D.S. Lakshmi, N. Trivedi, C.R.K. Reddy, Synthesis and characterization of seaweed cellulose derived carboxymethyl cellulose, Carbohydr. Polym. 157 (2017) 1604–1610, https://doi.org/10.1016/j.carbpol.2016.11.042.
[161] N. Wahlström, U. Edlund, H. Pavia, G. Toth, A. Jaworski, A.J. Pell, F.X. Choong, H. Shirani, K.P.R. Nilsson, A. Richter-Dahlfors, Cellulose from the green macroalgae Ulva lactuca: isolation, characterization, optotracing, and production of cellulose nanofibrils, Cellulose 27 (2020) 3707–3725, https://doi.org/10.1007/s10570-020-03029-5.
[162] S.P. LakshmiBalasubramaniam, C. Howell, M. Tajvidi, D. Skonberg, Characterization of novel cellulose nanofibril and phenolic acid-based active and hydrophobic packaging films, Food Chem. 374 (2022) 22–24, https://doi.org/10.1016/j.foodchem.2021.131773.
[163] M.J. Dunlop, B. Acharya, R. Bissessur, Isolation of nanocrystalline cellulose from tunicates, J. Environ. Chem. Eng. 6 (2018) 4408–4412, https://doi.org/10.1016/j.jece.2018.06.056.
[164] M.J. Dunlop, B. Acharya, R. Bissessur, Study of plant and tunicate based nanocrystalline cellulose in hybrid polymeric nanocomposites, Cellulose. 27 (2020) 249–261, https://doi.org/10.1007/s10570-019-02791-5.
[165] R. Araujo-Silva, A.C.O. Mafra, M.J. Rojas, W. Kopp, R. de C. Giordano, R. Fernandez-Lafuente, P.W. Tardioli, Maltose production using starch from cassava bagasse catalyzed by cross-linked β-amylase aggregates, Catalysts 8 (2018), https://doi.org/10.3390/catal8040170.
[166] K.Z. Hafila, R. Jumaidin, R.A. Ilyas, M.Z. Selamat, F.A.M. Yusof, Effect of palm wax on the mechanical, thermal, and moisture absorption properties of thermoplastic cassava starch composites, Int. J. Biol. Macromol. 194 (2022) 851–860, https://doi.org/10.1016/j.ijbiomac.2021.11.139.
[167] R. Lerdlattaporn, C. Phalakornkule, S. Trakulvichean, W. Songkasiri, Implementing circular economy concept by converting cassava pulp and wastewater to biogas for sustainable production in starch industry, Sustain. Environ. Res. 31 (2021), https://doi.org/10.1186/s42834-021-00093-9.
[168] M. Pirouzifard, R.A. Yorghanlu, S. Pirsa, Production of active film based on potato starch containing Zedo gum and essential oil of Salvia officinalis and study of physical, mechanical, and antioxidant properties, J. Thermoplast. Compos. Mater. 33 (2020) 915–937, https://doi.org/10.1177/0892705718815541.
[169] S. Reyniers, N. De Brier, S. Matthijs, K. Brijs, J.A. Delcour, Impact of mineral ions on the release of starch and gel forming capacity of potato flakes in relation to water dynamics and oil uptake during the production of snacks made thereof, Food Res. Int. 122 (2019) 419–431, https://doi.org/10.1016/j.foodres.2019.03.065.
[170] L.V.T. Vi, A. Salakkam, A. Reungsang, Optimization of key factors affecting biohydrogen production from sweet potato starch, Energy Procedia 138 (2017) 973–978.
[171] X. Sun, A.S.M. Saleh, Z. Sun, X. Ge, H. Shen, Q. Zhang, X. Yu, L. Yuan, W. Li, Modification of multi-scale structure, physicochemical properties, and digestibility of rice starch via microwave and cold plasma treatments, Lwt-Food Sci. Technol. 153 (2022), 112483, https://doi.org/10.1016/j.lwt.2021.112483.
[172] E. Agama-Acevedo, P.C. Flores-Silva, L.A. Bello-Perez, Cereal Starch Production for Food Applications, Elsevier Inc., 2018, https://doi.org/10.1016/B978-0-12-809440-2.00003-4.
[173] B.A. Ashwar, A. Gani, A. Gani, A. Shah, F.A. Masoodi, Production of RS4 from rice starch and its utilization as an encapsulating agent for targeted delivery of probiotics, Food Chem. 239 (2018) 287–294, https://doi.org/10.1016/j.foodchem.2017.06.110.
[174] M.J. Lindsay, T.W. Walker, J.A. Dumesic, S.A. Rankin, G.W. Huber, Production of monosaccharides and whey protein from acid whey waste streams in the dairy industry, Green Chem. 20 (2018) 1824–1834, https://doi.org/10.1039/c8gc00517f.
[175] Z. Jiang, Y. Gao, J. Li, K. Wang, C. Ma, D. Sun, M.A. Hussain, A. Qayum, J. Hou, Consecutive pH-shift and ultrasound treatment modify the physicochemical properties of whey protein isolate, Int. Dairy J. 127 (2022) 1–7, https://doi.org/10.1016/j.idairyj.2021.105211.
[176] X. Sui, T. Zhang, L. Jiang, Soy protein: molecular structure revisited and recent advances in processing technologies, Annu. Rev. Food Sci. Technol. 12 (2021) 119–147, https://doi.org/10.1146/annurev-food-062220-104405.
[177] M. Thrane, P.V. Paulsen, M.W. Orcutt, T.M. Krieger, Soy Protein: Impacts, Production, and Applications, Elsevier Inc., 2017, https://doi.org/10.1016/B978-0-12-802778-3.00002-0.
[178] Y. Wang, L. Serventi, Sustainability of dairy and soy processing: a review on wastewater recycling, J. Clean. Prod. 237 (2019) 1–7, https://doi.org/10.1016/j.jclepro.2019.117821.
[179] M.T. Masatcioglu, F. Koksel, Functional and thermal properties of yellow pea and red lentil extrudates produced by nitrogen gas injection assisted extrusion cooking, J. Sci. Food Agric. 99 (2019) 6796–6805, https://doi.org/10.1002/jsfa.9964.
[180] C. Kesre, M.T. Masatcioglu, Physical characteristics of corn extrudates supplemented with red lentil bran, Lwt-Food Sci. Technol. 153 (2022), 112530, https://doi.org/10.1016/j.lwt.2021.112530.
[181] S. Babacan Cevik, K. Kahraman, L. Ekici, Production of oven-baked wheat chips enriched with red lentil: an optimization study by response surface methodology, J. Food Sci. Technol. 59 (2022) 2243–2254, https://doi.org/10.1007/s13197-021-05237-8.
[182] E.A. Ashour, M.S. El-Kholy, M. Alagawany, M.E.A. El-Hack, L.A. Mohamed, A. E. Taha, A.I.E. Sheikh, V. Laudadio, V. Tufarelli, Effect of dietary supplementation with moringa oleifera leaves and/or seeds powder on production, egg characteristics, hatchability and blood chemistry of laying Japanese quails, Sustainability 12 (2020), https://doi.org/10.3390/su12062463.
[183] M.M.Y. Elghandour, L.H. Vallejo, A.Z.M. Salem, M. Mellado, L.M. Camacho, M. Cipriano, O.A. Olafadehan, J. Olivares, S. Rojas, Moringa oleifera leaf meal as an environmental friendly protein source for ruminants: Biomethane and carbon dioxide production, and fermentation characteristics, J. Clean. Prod. 165 (2017) 1229–1238, https://doi.org/10.1016/j.jclepro.2017.07.151.
[184] A. Jain, R. Subramanian, B. Manohar, C. Radha, Preparation, characterization and functional properties of Moringa oleifera seed protein isolate, J. Food Sci. Technol. 56 (2019) 2093–2104, https://doi.org/10.1007/s13197-019-03690-0.
[185] B.S. Yancheshmeh, M.A. Hesarinejad, N. Zamani, Z. Yousefi, A. Abdolshahi, A. J. Javan, Evaluation the physical properties of Vicia Villosa seed and Study the effect of defatting and pH on the physicochemical and functional properties of its, Iran. Food Sci. Technol. Res. J. 17 (2021) 543–557.
[186] D. Rechitean, M.N. Horablaga, G. Gorinoiu, G. Răducan, V. Sărăteanu, A. Agapie, Study of some qualitative parameters of hairy vetch with cereals winter crop mixtures cultivated in the conditions of western Romania (case study), Res. J. Agric. Sci. 52 (2020) 189–195.
[187] F.R. Attar, F. Rezagholi, M.A. Hesarinejad, Vicia Villosa protein isolate: a new source of protein to make a biodegradable film, Potravin. Slovak, J. Food Sci. 12 (2018) 461–471, https://doi.org/10.5219/913.
[188] P.A. Aneesh, R. Anandan, L.R.G. Kumar, K.K. Ajeeshkumar, K.A. Kumar, S. Mathew, A step to shell biorefinery—extraction of astaxanthin-rich oil, protein, chitin, and chitosan from shrimp processing waste, Biomass Convers. Biorefin. (2020) 1–19, https://doi.org/10.1007/s13399-020-01074-5.
[189] K. Divya, M.S. Jisha, Chitosan nanoparticles preparation and applications, Environ. Chem. Lett. 16 (2018) 101–112, https://doi.org/10.1007/s10311-017-0670-y.

[190] N. Hammi, S. Chen, C. Michon, S. Royer, A. El Kadib, Cu nanoparticles embedded on reticular chitosan-derived N-doped carbon: application to the catalytic hydrogenation of alkenes, alkynes and N-heteroarenes, Mol. Catal. 519 (2022) 22–24, https://doi.org/10.1016/j.mcat.2021.112104.
[191] J.R. Cadano, M. Jose, A.G. Lubi, J.N. Maling, J.S. Moraga, Q.Y. Shi, H. M. Vegafria, C.C. VinceCruz-Abeledo, A comparative study on the raw chitin and chitosan yields of common bio-waste from Philippine seafood, Environ. Sci. Pollut. Res. 28 (2021) 11954–11961, https://doi.org/10.1007/s11356-020-08380-5.
[192] J. Lu, X. Cong, Y. Li, Y. Hao, C. Wang, Scalable recycling of oyster shells into high purity calcite powders by the mechanochemical and hydrothermal treatments, J. Clean. Prod. 172 (2018) 1978–1985, https://doi.org/10.1016/j.jclepro.2017.11.228.
[193] S. Majekodunmi, E.-A. Akpan, Comparative study for in-vitro evaluation of metronidazole prepared using natural chitosan from oyster shells of Egeria radiata, Br. J. Pharm. Res. 17 (2017) 1–11, https://doi.org/10.9734/bjpr/2017/33247.
[194] A.C. De Lima Batista, F.E. De Souza Neto, W. De Souza Paiva, Review of fungal chitosan: past, present and perspectives in Brazil, Polimeros 28 (2018) 275–283, https://doi.org/10.1590/0104-1428.08316.
[195] K.M. Abdel-Gawad, A.F. Hifney, M.A. Fawzy, M. Gomaa, Technology optimization of chitosan production from Aspergillus niger biomass and its functional activities, Food Hydrocoll. 63 (2017) 593–601, https://doi.org/10.1016/j.foodhyd.2016.10.001.
[196] P.S. Bhavsar, G. Dalla Fontana, M. Zoccola, Sustainable superheated water hydrolysis of black soldier fly exuviae for chitin extraction and use of the obtained chitosan in the textile field, ACS Omega 6 (2021) 8884–8893, https://doi.org/10.1021/acsomega.0c06040.
[197] A. Jayanegara, R.P. Haryati, A. Nafisah, P. Suptijah, M. Ridla, E.B. Laconi, Derivatization of chitin and chitosan from black soldier fly (Hermetia illucens) and their use as feed additives: an in vitro study, Adv. Anim. Vet. Sci. 8 (2020) 472–477, https://doi.org/10.17582/JOURNAL.AAVS/2020/8.5.472.477.
[198] Y. Sun, Z. Xu, Y. Zheng, J. Zhou, Z. Xiu, Efficient production of lactic acid from sugarcane molasses by a newly microbial consortium CEE-DL15, Process Biochem. 81 (2019) 132–138, https://doi.org/10.1016/j.procbio.2019.03.022.
[199] T. Lopez-Arenas, O. Anaya-Reza, E.S. Perez-Cisneros, M. Sales-Cruz, Conceptual design of sugarcane biorefinery upgrading molasses to value-added chemicals, in: A-Z Biorefinery A Compr. View., 2022, pp. 683–712, https://doi.org/10.1016/B978-0-12-819248-1.00003-8.
[200] M. Aghbashlo, M. Mandegari, M. Tabatabaei, S. Farzad, M. Mojarab Soufiyan, J. F. Görgens, Exergy analysis of a lignocellulosic-based biorefinery annexed to a sugarcane mill for simultaneous lactic acid and electricity production, Energy 149 (2018) 623–638, https://doi.org/10.1016/j.energy.2018.02.063.
[201] A. Arai, A. Igoshi, A. Inoue, K. Noda, S. Tsutsuura, M. Murata, Relationship between lactose utilization of lactic acid bacteria and browning of cheese during storage, Biosci. Biotechnol. Biochem. 84 (2020) 1886–1893, https://doi.org/10.1080/09168451.2020.1768508.
[202] V. Panagopoulos, K. Boura, A. Dima, I.K. Karabagias, L. Bosnea, P.S. Nigam, M. Kanellaki, A.A. Koutinas, Consolidated bioprocessing of lactose into lactic acid and ethanol using non-engineered cell factories, Bioresour. Technol. 345 (2022) 1–8, https://doi.org/10.1016/j.biortech.2021.126464.
[203] T.L. Turner, E. Kim, C.H. Hwang, G.C. Zhang, J.J. Liu, Y.S. Jin, Short communication: conversion of lactose and whey into lactic acid by engineered yeast, J. Dairy Sci. 100 (2017) 124–128, https://doi.org/10.3168/jds.2016-11784.
[204] K. Yao, Q. Xing Zhou, D. Mei Liu, S. Min Chen, K. Yuan, Comparative proteomics of the metabolic pathways involved in L-lactic acid production in Bacillus coagulans BCS13002 using different carbon sources, Lwt. 116 (2019) 2019–2021, https://doi.org/10.1016/j.lwt.2019.108445.
[205] K. Okano, G. Uematsu, S. Hama, T. Tanaka, H. Noda, A. Kondo, K. Honda, Metabolic engineering of Lactobacillus plantarum for direct l-Lactic acid production from raw corn starch, Biotechnol. J. 13 (2018) 29393585, https://doi.org/10.1002/biot.201700517.
[206] S. Ouyang, L. Zou, H. Qiao, J. Shi, Z. Zheng, J. Ouyang, One-pot process for lactic acid production from wheat straw by an adapted Bacillus coagulans and identification of genes related to hydrolysate-tolerance, Bioresour. Technol. 315 (2020) 1–8, https://doi.org/10.1016/j.biortech.2020.123855.
[207] D. Cizeikiene, G. Juodeikiene, J. Damasius, Use of wheat straw biomass in production of L-lactic acid applying biocatalysis and combined lactic acid bacteria strains belonging to the genus Lactobacillus, Biocatal. Agric. Biotechnol. 15 (2018) 185–191, https://doi.org/10.1016/j.bcab.2018.06.015.
[208] C.E. Ochoa-Velasco, J.C. Pérez-Pérez, J.M. Varillas-Torres, A.R. Navarro-Cruz, P. Hernández-Carranza, R. Munguía-Pérez, T.S. Cid-Pérez, R. Avila-Sosa, Starch edible films/coatings added with carvacrol and thymol: In vitro and in vivo evaluation against colletotrichum gloeosporioides, Foods 10 (2021) 22–23, https://doi.org/10.3390/foods10010175.
[209] S. Rani, R. Kumar, A review on material and antimicrobial properties of soy protein isolate film, J. Polym. Environ. 27 (2019) 1613–1628, https://doi.org/10.1007/s10924-019-01456-5.
[210] H. Tian, G. Guo, X. Fu, Y. Yao, L. Yuan, A. Xiang, Fabrication, properties and applications of soy-protein-based materials: a review, Int. J. Biol. Macromol. 120 (2018) 22–24, https://doi.org/10.1016/j.ijbiomac.2018.08.110.
[211] J. Yang, I. Faber, C.C. Berton-Carabin, C.V. Nikiforidis, E. van der Linden, L.M. C. Sagis, Foams and air-water interfaces stabilised by mildly purified rapeseed proteins after defatting, Food Hydrocoll. 112 (2021), 106270, https://doi.org/10.1016/j.foodhyd.2020.106270.
[212] S. Yadav, G.K. Mehrotra, P.K. Dutta, Chitosan based ZnO nanoparticles loaded gallic-acid films for active food packaging, Food Chem. 334 (2021) 2021–2023, https://doi.org/10.1016/j.foodchem.2020.127605.
[213] Z. Liu, H. Lu, H. Zhang, L. Li, Poly (vinyl alcohol)/polylactic acid blend film with enhanced processability, compatibility, and mechanical property fabricated via melt processing, J. Appl. Polym. Sci. 138 (2021) 1–11, https://doi.org/10.1002/app.51204.
[214] Z. Liu, D. Hu, L. Huang, W. Li, J. Tian, L. Lu, C. Zhou, Simultaneous improvement in toughness, strength and biocompatibility of poly(lactic acid) with polyhedral oligomeric silsesquioxane, Chem. Eng. J. 346 (2018) 649–661, https://doi.org/10.1016/j.cej.2018.03.077.
[215] O.M. Sanusi, A. Benelfellah, Z. Terzopoulou, D.N. Bikiaris, Properties of poly (lactic acid)/ montmorillonite / carbon nanotubes nanocomposites: determination of percolation threshold, J. Mater. Sci. 56 (2021) 16887–16901, https://doi.org/10.1007/s10853-021-06378-z.
[216] S. Kashani Rahimi, R. Aeinehvand, K. Kim, J.U. Otaigbe, Structure and biocompatibility of bioabsorbable nanocomposites of aliphatic-aromatic copolyester and cellulose nanocrystals, Biomacromolecules 18 (2017) 2179–2194, https://doi.org/10.1021/acs.biomac.7b00578.
[217] A.R. de Matos Costa, A. Crocitti, L.H. de Carvalho, S.C. Carroccio, P. Cerruti, G. Santagata, Properties of biodegradable films based on poly(Butylene succinate) (pbs) and poly(butylene adipate-co-terephthalate) (pbat) blends, Polymers (Basel) 12 (2020) 1–17, https://doi.org/10.3390/polym12102317.
[218] D. Qureshi, S.K. Nayak, A. Anis, S.S. Ray, D. Kim, T.T. Hanh Nguyen, K. Pal, Introduction of biopolymers: Food and biomedical applications, Biopolym. Formul. Biomed. Food Appl. (2020) 1–45, https://doi.org/10.1016/B978-0-12-816897-4.00001-1.
[219] J.O. de Moraes, A.S. Scheibe, B. Augusto, M. Carciofi, J.B. Laurindo, Conductive drying of starch-fiber films prepared by tape casting: drying rates and film properties, LWT-Food Sci. Technol. 64 (2015) 356–366.
[220] A.S. Scheibe, J.O. de Moraes, J.B. Laurindo, Production and characterization of bags from biocomposite films of starch-vegetal fibers prepared by tape casting, J. Food Process Eng. 37 (2014) 482–492.
[221] A.D. Adamu, S.S. Jikan, B.H.A. Talip, N.A. Badarulzaman, S. Yahaya, Effect of glycerol on the properties of tapioca starch film, Mater. Sci. Forum 888 MSF (2017) 239–243, https://doi.org/10.4028/www.scientific.net/MSF.888.239.
[222] L. Deng, X. Kang, Y. Liu, F. Feng, H. Zhang, Characterization of gelatin/zein films fabricated by electrospinning vs solvent casting, Food Hydrocoll. 74 (2018) 324–332, https://doi.org/10.1016/j.foodhyd.2017.08.023.
[223] C. Luz, J. Calpe, F. Saladino, F.B. Luciano, M. Fernandez-Franzón, J. Mañes, G. Meca, Antimicrobial packaging based on ε-polylysine bioactive film for the control of mycotoxigenic fungi in vitro and in bread, J. Food Process. Preserv. 42 (2018) 22–23, https://doi.org/10.1111/jfpp.13370.
[224] J. Zhang, C. Cao, Y. Wang, L. Xie, W. Li, B. Li, R. Guo, H. Yan, Magnesium oxide / silver nanoparticles reinforced poly(butylene succinate- co -terephthalate) biofilms for food packaging applications, Food Packag. Shelf Life 30 (2021) (December 2021) 2021–2024, https://doi.org/10.1016/j.fpsl.2021.100748, 100748 Magnes. 30.
[225] C. Swaroop, M. Shukla, Nano-magnesium oxide reinforced polylactic acid biofilms for food packaging applications, Int. J. Biol. Macromol. 113 (2018) 729–736, https://doi.org/10.1016/j.ijbiomac.2018.02.156.
[226] M.P. Pranata, J. González-Buesa, S. Chopra, K. Kim, Y. Pietri, P.K.W. Ng, L. M. Matuana, E. Almenar, Egg white protein film production through extrusion and calendering processes and its suitability for food packaging applications, Food Bioprocess Technol. 12 (2019) 714–727, https://doi.org/10.1007/s11947-019-2248-0.
[227] V.M. Azevedo, S.V. Borges, J.M. Marconcini, M.I. Yoshida, A.R.S. Neto, T. C. Pereira, C.F.G. Pereira, Effect of replacement of corn starch by whey protein isolate in biodegradable film blends obtained by extrusion, Carbohydr. Polym. 157 (2017) 971–980, https://doi.org/10.1016/j.carbpol.2016.10.046.
[228] G. Li, S. Shankar, J.W. Rhim, B.Y. Oh, Effects of preparation method on properties of poly(butylene adipate-co-terephthalate) films, Food Sci. Biotechnol. 24 (2015) 1679–1685, https://doi.org/10.1007/s10068-015-0218-5.
[229] J.M. Quiroz-Castillo, D.E. Rodríguez-Félix, J. Romero-García, T.J. Madera-Santana, J.C. Encinas-Encinas, M.M. Castillo-Ortega, D. Cabrera-Germán, L. L. Lizárraga-Laborín, Extrusion of polypropylene/chitosan/poly (lactic-acid) films: chemical, mechanical, and thermal properties, J. Appl. Polym. Sci. 138 (2021) 49850.
[230] W.N. Gilfilla, L. Moghaddam, J. Bartley, W.O.S. Doherty, Thermal extrusion of starch film with alcohol, J. Food Eng. 170 (2016) 92–99, https://doi.org/10.1016/j.jfoodeng.2004.11.008.
[231] W. Yang, Y. Zhang, T. Liu, R. Huang, S. Chai, F. Chen, Q. Fu, Completely green approach for the preparation of strong and highly conductive graphene composite film by using nanocellulose as dispersing agent and mechanical compression, ACS Sustain. Chem. Eng. 5 (2017) 9102–9113, https://doi.org/10.1021/acssuschemeng.7b02012.
[232] T.B. Rouf, J.L. Kokini, Natural biopolymer-based nanocomposite films for packaging applications, Bionanocompos. Packag. Appl. (2017) 149–177, https://doi.org/10.1007/978-3-319-67319-6_8.
[233] C. Okolieocha, D. Raps, K. Subramaniam, V. Altstädt, Microcellular to nanocellular polymer foams: progress (2004-2015) and future directions - a review, Eur. Polym. J. 73 (2015) 500–519, https://doi.org/10.1016/j.eurpolymj.2015.11.001.
[234] J.E. Bautista-Del-Ángel, A.B. Morales-Cepeda, P.M. Wood-Adams, Compatibility, crystallinity and mechanical properties of poly(lactic acid)-poly(ether-block-

amide) based copper nanocomposites, Polym. Int. 69 (2020) 1024–1037, https://doi.org/10.1002/pi.6058.
[235] M. Li, Y. Ren, D. Lee, S. Choi, Crystallization behavior and electrical properties of nanoparticle-reinforced poly(lactic acid)-based films, Polymers (Basel) 14 (2022) 177, https://doi.org/10.3390/polym14010177.
[236] H. Rashidi, B. Najaf Oshani, I. Hejazi, J. Seyfi, Tuning crystallization and hydrolytic degradation behaviors of poly(lactic acid) by using silver phosphate, zinc oxide and their nano-hybrids, Polym. Technol. Mater. 59 (2020) 72–82, https://doi.org/10.1080/25740881.2019.1625382.
[237] N.A. Sirotkin, D.L. Gurina, A.V. Khlyustova, D.Y. Costerin, I.K. Naumova, V. A. Titov, A.V. Agafonov, Experimental and computational investigation of polylactic acid/silver-NP nanocomposite with antimicrobial activity prepared by plasma in liquid, Plasma Process. Polym. 18 (2021) 1–17, https://doi.org/10.1002/ppap.202000169.
[238] I. Kim, K. Viswanathan, G. Kasi, K. Sadeghi, S. Thanakkasaranee, J. Seo, Poly (lactic acid) / ZnO bionanocomposite films with positively charged ZnO as potential antimicrobial food packaging materials, Polymers (Basel). 11 (2019) 1427, https://doi.org/10.3390/polym11091427.
[239] S. Li, G. Chen, S. Qiang, Z. Yin, Z. Zhang, Y. Chen, Synthesis and evaluation of highly dispersible and efficient photocatalytic TiO2/poly lactic acid nanocomposite films via sol-gel and casting processes, Int. J. Food Microbiol. 331 (2020) 2020–2023, https://doi.org/10.1016/j.ijfoodmicro.2020.108763.
[240] S. Kazemi-Pasarvi, N.G. Ebrahimi, M. Raef, Preparation, characterization, and permeability of novel poly (lactic acid)-based blends filled with thymol and ZnO, Polym. Test. 89 (2020), 106550.
[241] Y. Lei, L. Mao, J. Yao, Z. Li, Efficient gas barrier and antibacterial properties of poly(lactic acid) nanocomposites: Functionalization with phytic Acid-Cu(II) loaded layered clay, Materials (Basel) 13 (2020) 22–23, https://doi.org/10.3390/MA13092033.
[242] J. Yu, D. Wang, N. Geetha, K.M. Khawar, S. Jogaiah, M. Mujtaba, Current trends and challenges in the synthesis and applications of chitosan-based nanocomposites for plants: a review, Carbohydr. Polym. 261 (2021) 1–4, https://doi.org/10.1016/j.carbpol.2021.117904.
[243] M. Kaseem, K. Hamad, Z.U. Rehman, Review of recent advances in polylactic acid/TiO2 composites, Materials (Basel) 12 (2019), https://doi.org/10.3390/ma12223659.
[244] F.F. Ge, C.H. Tsou, S. Yuan, M.R. De Guzman, C.Y. Zeng, J. Li, C.F. Jia, B. Y. Cheng, P.C. Yang, C. Gao, Barrier performance and biodegradability of antibacterial poly(butylene adipate-co-terephthalate) nanocomposites reinforced with a new MWCNT-ZnO nanomaterial, Nanotechnology 32 (2021), 34359060, https://doi.org/10.1088/1361-6528/ac1b52.
[245] A.F. Jaramillo, S.A. Riquelme, G. Sánchez-Sanhueza, C. Medina, F. Solís-Pomar, D. Rojas, C. Montalba, M.F. Melendrez, E. Pérez-Tijerina, Comparative study of the antimicrobial effect of nanocomposites and composite based on poly(butylene adipate-co-terephthalate) using Cu and Cu/Cu2O nanoparticles and CuSO4, Nanoscale Res. Lett. 14 (2019) 22–23, https://doi.org/10.1186/s11671-019-2987-x.
[246] S. Zhou, X. Zhai, R. Zhang, W. Wang, L.T. Lim, H. Hou, High-throughput fabrication of antibacterial starch/pbat/agnps@sio2 films for food packaging, Nanomaterials 11 (2021) 22–23, https://doi.org/10.3390/nano11113062.
[247] J. Zhang, C. Cao, S. Zheng, W. Li, B. Li, X. Xie, Poly (butylene adipate- co -terephthalate)/ magnesium oxide / silver ternary composite biofilms for food packaging application, Food Packag. Shelf Life 24 (2020), 100487, https://doi.org/10.1016/j.fpsl.2020.100487.
[248] N. Verma, K. Pramanik, A.K. Singh, A. Biswas, Design of magnesium oxide nanoparticle incorporated carboxy methyl cellulose/poly vinyl alcohol composite film with novel composition for skin tissue engineering, Mater. Technol. 37 (2022) 706–716, https://doi.org/10.1080/10667857.2021.1873634.
[249] A.M. Mostafa, V.F. Lotfy, E.A. Mwafy, A.H. Basta, Influence of coating by Cu and Ag nanoparticles via pulsed laser deposition technique on optical, electrical and mechanical properties of cellulose paper, J. Mol. Struct. 1203 (2020) 1–4, https://doi.org/10.1016/j.molstruc.2019.127472.
[250] S. Roy, J.-W. Rhim, Carboxymethyl cellulose-based antioxidant and antimicrobial active packaging film incorporated with curcumin and zinc oxide, Int. J. Biol. Macromol. 148 (2020) 666–676.
[251] K. Chen, J. Yu, J. Huang, Q. Tang, H. Li, Z. Zou, Improved mechanical, water vapor barrier and UV-shielding properties of cellulose acetate films with flower-like metal-organic framework nanoparticles, Int. J. Biol. Macromol. 167 (2021) 1–9.
[252] H. Hajizadeh, S.J. Peighambardoust, S.H. Peighambardoust, D. Peressini, Physical, mechanical, and antibacterial characteristics of bio-nanocomposite films loaded with Ag-modified SiO2 and TiO2 nanoparticles, J. Food Sci. 85 (2020) 1193–1202, https://doi.org/10.1111/1750-3841.15079.
[253] M. Alizadeh-Sani, E. Moghaddas Kia, Z. Ghasempour, A. Ehsani, Preparation of active nanocomposite film consisting of sodium caseinate, ZnO nanoparticles and rosemary essential oil for food packaging applications, J. Polym. Environ. 29 (2021) 588–598, https://doi.org/10.1007/s10924-020-01906-5.
[254] N. Srikhao, P. Kasemsiri, A. Ounkaew, N. Lorwanishpaisarn, M. Okhawilai, U. Pongsa, S. Hiziroglu, P. Chindaprasirt, Bioactive nanocomposite film based on cassava starch/polyvinyl alcohol containing green synthesized silver nanoparticles, J. Polym. Environ. 29 (2021) 672–684, https://doi.org/10.1007/s10924-020-01909-2.
[255] S. Shankar, J.W. Rhim, Effect of types of zinc oxide nanoparticles on structural, mechanical and antibacterial properties of poly(lactide)/poly(butylene adipate-co-terephthalate) composite films, Food Packag. Shelf Life. 21 (2019) 2019–2022, https://doi.org/10.1016/j.fpsl.2019.100327.
[256] V. Ramji, M. Vishnuvarthanan, Influence of NiO supported silica nanoparticles on mechanical, barrier, optical and antibacterial properties of polylactic acid (PLA) bio nanocomposite films for food packaging applications, Silicon 14 (2022) 531–538, https://doi.org/10.1007/s12633-020-00839-x.
[257] M.S. Nasab, M. Tabari, M.H. Azizi, Morphological and mechanical properties of poly (lactic acid)/zinc oxide nanocomposite films, Nanomedicine Res. J. 3 (2018) 96–101, https://doi.org/10.22034/NMRJ.2018.02.006.
[258] D. Phothisarattana, P. Wongphan, K. Promhuad, J. Promsorn, N. Harnkarnsujarit, Biodegradable poly(butylene adipate-co-terephthalate) and thermoplastic starch-blended tio2 nanocomposite blown films as functional active packaging of fresh fruit, Polymers (Basel). 13 (2021), https://doi.org/10.3390/polym13234192.
[259] L. Lai, J. Li, P. Liu, L. Wu, S.J. Severtson, W. Wang, Mechanically reinforced biodegradable poly (butylene adipate-co- terephthalate) with interactive nanoinclusions, Polymer (Guildf). 197 (2020) 1–4, https://doi.org/10.1016/j.polymer.2020.122518.
[260] K. Charoensri, C. Rodwihok, S.H. Ko, D. Wongratanaphisan, H.J. Park, Enhanced antimicrobial and physical properties of poly (butylene adipate-co-terephthalate)/zinc oxide/reduced graphene oxide ternary nanocomposite films, Mater. Today Commun. 28 (2021), 102586, https://doi.org/10.1016/j.mtcomm.2021.102586.
[261] M.P. Indumathi, K. Saral Sarojini, G.R. Rajarajeswari, Antimicrobial and biodegradable chitosan/cellulose acetate phthalate/ZnO nano composite films with optimal oxygen permeability and hydrophobicity for extending the shelf life of black grape fruits, Int. J. Biol. Macromol. 132 (2019) 1112–1120, https://doi.org/10.1016/j.ijbiomac.2019.03.171.
[262] M.I. Wahba, Enhancement of the mechanical properties of chitosan, J. Biomater. Sci. Polym. Ed. 0 (2019) 1–26, https://doi.org/10.1080/09205063.2019.1692641.
[263] C. Rodrigues, J.M.M. de Mello, F. Dalcanton, D.L.P. Macuvele, N. Padoin, M. A. Fiori, C. Soares, H.G. Riella, Mechanical, thermal and antimicrobial properties of chitosan-based-nanocomposite with potential applications for food packaging, J. Polym. Environ. 28 (2020) 1216–1236, https://doi.org/10.1007/s10924-020-01678-y.
[264] P. De Chitosan, Effect of chemical modification of titanium dioxide particles via silanization under properties of chitosan/potato-starch films efecto de la modificación química de las partículas de dióxido de titanio mediante silanización sobre las propiedades de LAS, Rev. Mex. Ing. Quím. vol. 18 (2019) 913–927.
[265] N.Z. Tomić, Thermal studies of compatibilized polymer blends, Compat, Polym. Blends Micro Nano Scale Phase Morphol. Interphase Charact. Prop. (2019) 489–510, https://doi.org/10.1016/B978-0-12-816006-0.00017-7.
[266] K. Król-Morkisz, K. Pielichowska, Thermal Decomposition of Polymer Nanocomposites With Functionalized Nanoparticles, Elsevier Inc., 2018, https://doi.org/10.1016/B978-0-12-814064-2.00013-5.
[267] S. Roy, J.-W. Rhim, Effect of CuS reinforcement on the mechanical, water vapor barrier, UV-light barrier, and antibacterial properties of alginate-based composite films, Int. J. Biol. Macromol. 164 (2020) 37–44.
[268] A. Rozilah, C.N. Aiza Jaafar, S.M. Sapuan, I. Zainol, R.A. Ilyas, The effects of silver nanoparticles compositions on the mechanical, physiochemical, antibacterial, and morphology properties of sugar palm starch biocomposites for antibacterial coating, Polymers (Basel). 12 (2020) 1–21, https://doi.org/10.3390/polym12112605.
[269] J. Zhu, W. Gao, B. Wang, X. Kang, P. Liu, B. Cui, A.M. Abd El-Aty, Preparation and evaluation of starch-based extrusion-blown nanocomposite films incorporated with nano-ZnO and nano-SiO2, Int. J. Biol. Macromol. 183 (2021) 1371–1378, https://doi.org/10.1016/j.ijbiomac.2021.05.118.
[270] J. Vallejo-Montesinos, J. Gámez-Cordero, R. Zarraga, M.C. Pérez Pérez, J. A. Gonzalez-Calderon, Influence of the surface modification of titanium dioxide nanoparticles TiO2 under efficiency of silver nanodots deposition and its effect under the properties of starch–chitosan (SC) films, Polym. Bull. 77 (2020) 107–133, https://doi.org/10.1007/s00289-019-02740-z.
[271] D.S. Bajwa, J. Shojaeiarani, J.D. Liaw, S.G. Bajwa, Role of hybrid nano-zinc oxide and cellulose nanocrystals on the mechanical, thermal, and flammability properties of poly (lactic acid) polymer, J. Compos. Sci. 5 (2021), https://doi.org/10.3390/jcs5020043.
[272] R.C. de Azevedo Gonçalves Mota, L.R. de Menezes, E.O. da Silva, Poly(lactic acid) polymers containing silver and titanium dioxide nanoparticles to be used as scaffolds for bioengineering, J. Mater. Res. 36 (2021) 406–419. doi:https://doi.org/10.1557/s43578-020-00038-9.
[273] F. Zahiri Oghani, K. Tahvildari, M. Nozari, Novel antibacterial food packaging based on chitosan loaded ZnO nano particles prepared by green synthesis from nettle leaf extract, J. Inorg. Organomet. Polym. Mater. 31 (2021) 43–54, https://doi.org/10.1007/s10904-020-01621-7.
[274] J. Tarique, S.M. Sapuan, A. Khalina, Effect of glycerol plasticizer loading on the physical, mechanical, thermal, and barrier properties of arrowroot (Maranta arundinacea) starch biopolymers, Sci. Rep. 11 (2021) 1–17, https://doi.org/10.1038/s41598-021-93094-y.
[275] H.E. Salama, M.S. Abdel Aziz, Optimized carboxymethyl cellulose and guanidinylated chitosan enriched with titanium oxide nanoparticles of improved UV-barrier properties for the active packaging of green bell pepper, Int. J. Biol. Macromol. 165 (2020) 1187–1197, https://doi.org/10.1016/j.ijbiomac.2020.09.254.
[276] E. Jamróz, P. Kulawik, P. Kopel, The effect of nanofillers on the functional properties of biopolymer-based films: a review, Polymers (Basel). 11 (2019) 1–43, https://doi.org/10.3390/polym11040675.

[277] D. Qin, X. Ma, B. Zhang, Q. Luo, H. Na, J. Chen, J. Zhu, Ultra-high gas barrier and enhanced mechanical properties of corn cellulose nanocomposite films filled with graphene oxide nanosheets, Carbohydr. Polym. Technol. Appl. 2 (2021), 100066, https://doi.org/10.1016/j.carpta.2021.100066.
[278] S. Tavakolian, H. Ahari, M.H. Givianrad, H. Hosseini, Improving the Barrier Properties of Food Packaging by Al2O3@ TiO2 & Al2O3@ SiO2 Nanoparticles, Food Bioprocess Technol. 14 (2021) 1287–1300.
[279] Y. He, H. Li, X. Fei, L. Peng, Carboxymethyl cellulose/cellulose nanocrystals immobilized silver nanoparticles as an effective coating to improve barrier and antibacterial properties of paper for food packaging applications, Carbohydr. Polym. 252 (2021) 2021–2023, https://doi.org/10.1016/j.carbpol.2020.117156.
[280] D. Praseptiangga, N. Mufida, C. Panatarani, I.M. Joni, Enhanced multi functionality of semi-refined iota carrageenan as food packaging material by incorporating SiO2 and ZnO nanoparticles, Heliyon 7 (2021), https://doi.org/10.1016/j.heliyon.2021.e06963.
[281] L. Roufegarinejad, Development and characterization of the reinforced soy protein isolate-based nanocomposite film with CuO and TiO2 nanoparticles, J. Polym. Environ. 30 (2022) 2507–2515, https://doi.org/10.1007/s10924-022-02374-9.
[282] S.W. Lee, N.S. Said, N.M. Sarbon, The effects of zinc oxide nanoparticles on the physical, mechanical and antimicrobial properties of chicken skin gelatin/tapioca starch composite films in food packaging, J. Food Sci. Technol. 58 (2021) 4294–4302, https://doi.org/10.1007/s13197-020-04904-6.
[283] Z. Mehmood, M.B. Sadiq, M.R. Khan, Gelatin nanocomposite films incorporated with magnetic iron oxide nanoparticles for shelf life extension of grapes, J. Food Saf. 40 (2020) 3–5, https://doi.org/10.1111/jfs.12814.
[284] M. Jiménez-Rosado, V. Perez-Puyana, P. Sánchez-Cid, A. Guerrero, A. Romero, Incorporation of zno nanoparticles into soy protein-based bioplastics to improve their functional properties, Polymers (Basel). 13 (2021) 1–14, https://doi.org/10.3390/polym13040486.
[285] S.N. Mousavi, H. Daneshvar, M.S.S. Dorraji, Z. Ghasempour, V. Panahi-Azar, A. Ehsani, Starch / alginate / Cu-g-C 3 N 4 nanocomposite film for food packaging, Mater. Chem. Phys. 267 (2021), 124583, https://doi.org/10.1016/j.matchemphys.2021.124583.
[286] P.K. Dara, M. R., S.G. K., K. Deekonda, V. S., A. Rangasamy, S. Mathew, R.C. N., Biomodulation of poly (vinyl alcohol)/starch polymers into composite-based hybridised films: physico-chemical, structural and biocompatibility characterization, J. Polym. Res. 28 (2021) 1–13, https://doi.org/10.1007/s10965-021-02578-y.
[287] Z. Tang, F. Fan, Z. Chu, C. Fan, Y. Qin, Barrier properties and characterizations of poly(lactic Acid)/ZnO nanocomposites, Molecules. 25 (2020) 1–2, https://doi.org/10.3390/molecules25061310.
[288] T. Jamnongkan, A. Yosta, B. Thanesthakul, M. Sugimoto, T. Hara, Y. Takatsuka, R. Mongkholrattanasit, Effect of ZnO nanoparticles on the physical properties of PLA/PBS biocomposite films, Mater. Sci. Forum 1033 MSF (2021) 143–150, https://doi.org/10.4028/www.scientific.net/MSF.1033.143.
[289] M.P. Calderaro, C.I.G. de Luca Sarantopóulos, E.M.S. Sanchez, A.R. Morales, PBAT/hybrid nanofillers composites—Part 1: Oxygen and water vapor permeabilities, UV barrier and mechanical properties, J. Appl. Polym. Sci. 137 (2020) 1–12, https://doi.org/10.1002/app.49522.
[290] C. Cao, Y. Wang, S. Zheng, J. Zhang, W. Li, B. Li, R. Guo, J. Yu, Poly (butylene adipate-co-terephthalate)/titanium dioxide/silver composite biofilms for food packaging application, Lwt. 132 (2020) 2020–2023, https://doi.org/10.1016/j.lwt.2020.109874.
[291] S. Roy, L. Zhai, H.C. Kim, D.H. Pham, H. Alrobei, J. Kim, Tannic-acid-cross-linked and TiO2-nanoparticle-reinforced chitosan-based nanocomposite film, Polymers (Basel). 13 (2021) 228.
[292] E.M. Hussein, W.M. Desoky, M.F. Hanafy, O.W. Guirguis, Effect of TiO2 nanoparticles on the structural configurations and thermal, mechanical, and optical properties of chitosan/TiO2 nanoparticle composites, J. Phys. Chem. Solids 152 (2021) 2–5, https://doi.org/10.1016/j.jpcs.2021.109983.
[293] V.G.L. Souza, M.M. Alves, C.F. Santos, I.A.C. Ribeiro, C. Rodrigues, I. Coelhoso, A. L. Fernando, Biodegradable chitosan films with ZnO nanoparticles synthesized using food industry by-products—production and characterization, Coatings 11 (2021), https://doi.org/10.3390/coatings11060646.
[294] S. Shankar, D. Khodaei, M. Lacroix, Effect of chitosan/essential oils/silver nanoparticles composite films packaging and gamma irradiation on shelf life of strawberries, Food Hydrocoll. 117 (2021) 1–8, https://doi.org/10.1016/j.foodhyd.2021.106750.
[295] K.-K.S.P.E. Hernández, I.M.M.-M.J.D. Vázquez, M. Lepe, Y. Kovalenko, et al., Eur. Polym. J. 67 (2015) 242–251.
[296] D. Chouhan, P. Mandal, Applications of chitosan and chitosan based metallic nanoparticles in agrosciences-A review, Int. J. Biol. Macromol. 166 (2021) 1554–1569.
[297] L. Erlantz, U. Goikuria, J.L. Vilas, F. Cristofaro, G. Bruni, E. Fortunati, I. Armentano, L. Visai, L. Torre, Metal Nanoparticles Embedded in Cellulose Nanocrystal Based Films: Material Properties and Postuse Analysis, 2018.
[298] S.M.K. Thiagamani, N. Rajini, S. Siengchin, A.V. Rajulu, N. Hariram, N. Ayrilmis, Influence of silver nanoparticles on the mechanical, thermal and antimicrobial properties of cellulose-based hybrid nanocomposites, Compos. Part B Eng. 165 (2019) 516–525.
[299] E.S. Madivoli, P.G. Kareru, J. Gichuki, M.M. Elbagoury, Cellulose nanofibrils and silver nanoparticles enhances the mechanical and antimicrobial properties of polyvinyl alcohol nanocomposite film, Sci. Rep. 12 (2022) 19005.
[300] Y. Xie, Y. Pan, P. Cai, Cellulose-based antimicrobial films incroporated with ZnO nanopillars on surface as biodegradable and antimicrobial packaging, Food Chem. 368 (2022), 130784.
[301] L. Valencia, S. Kumar, E.M. Nomena, G. Salazar-Alvarez, A.P. Mathew, In-situ growth of metal oxide nanoparticles on cellulose nanofibrils for dye removal and antimicrobial applications, ACS Appl. Nano Mater. 3 (2020) 7172–7181.
[302] M.E. David, R.M. Ion, R.M. Grigorescu, L. Iancu, A.M. Holban, F. Iordache, A. I. Nicoara, E. Alexandrescu, R. Somoghi, S. Teodorescu, Biocompatible and antimicrobial cellulose acetate-collagen films containing MWCNTs decorated with TiO2 nanoparticles for potential biomedical applications, Nanomaterials. 12 (2022) 239.
[303] S.J. Peighambardoust, S.H. Peighambardoust, N. Pournasir, P.M. Pakdel, Properties of active starch-based films incorporating a combination of Ag, ZnO and CuO nanoparticles for potential use in food packaging applications, Food Packag. Shelf Life 22 (2019), 100420.
[304] S. Mousazadeh, A. Ehsani, E.M. Kia, Z. Ghasempour, Zinc oxide nanoparticles and periodate oxidation in developing pH-sensitive packaging film based on modified gelatin, Food Packag. Shelf Life 28 (2021), 100654.
[305] S.N. Hosseini, S. Pirsa, J. Farzi, Biodegradable nano composite film based on modified starch-albumin/MgO; antibacterial, antioxidant and structural properties, Polym. Test. 97 (2021), 107182.
[306] A.A. Ahmad, N.M. Sarbon, A comparative study: physical, mechanical and antibacterial properties of bio-composite gelatin films as influenced by chitosan and zinc oxide nanoparticles incorporation, Food Biosci. 43 (2021), 101250.
[307] J. Venkatesan, J.-Y. Lee, D.S. Kang, S. Anil, S.-K. Kim, M.S. Shim, D.G. Kim, Antimicrobial and anticancer activities of porous chitosan-alginate biosynthesized silver nanoparticles, Int. J. Biol. Macromol. 98 (2017) 515–525.
[308] S. Lotfi, H. Ahari, R. Sahraeyan, The effect of silver nanocomposite packaging based on melt mixing and sol–gel methods on shelf life extension of fresh chicken stored at 4 C, J. Food Saf. 39 (2019), e12625.
[309] S. Jafarzadeh, S.M. Jafari, Impact of metal nanoparticles on the mechanical, barrier, optical and thermal properties of biodegradable food packaging materials, Crit. Rev. Food Sci. Nutr. 61 (2021) 2640–2658.
[310] S. Sethi, S. Thakur, B.S. Kaith, N. Sharma, S. Ansar, S. Pandey, V. Kuma, Biopolymer starch-gelatin embedded with silver nanoparticle–based hydrogel composites for antibacterial application, Biomass Convers. Biorefinery. (2022) 1–22.
[311] M.M. Hasan, M.A. Shenashen, M.N. Hasan, H. Znad, M.S. Salman, M.R. Awual, Natural biodegradable polymeric bioadsorbents for efficient cationic dye encapsulation from wastewater, J. Mol. Liq. 323 (2021), 114587.
[312] A. Islam, S.H. Teo, Y.H. Taufiq-Yap, C.H. Ng, D.-V.N. Vo, M.L. Ibrahim, M. M. Hasan, M.A.R. Khan, A.S.M. Nur, M.R. Awual, Step towards the sustainable toxic dyes removal and recycling from aqueous solution-a comprehensive review, Resour. Conserv. Recycl. 175 (2021), 105849.
[313] M.R. Awual, Novel conjugated hybrid material for efficient lead (II) capturing from contaminated wastewater, Mater. Sci. Eng. C. 101 (2019) 686–695.
[314] M.R. Awual, A novel facial composite adsorbent for enhanced copper (II) detection and removal from wastewater, Chem. Eng. J. 266 (2015) 368–375.
[315] K.T. Kubra, M.S. Salman, M.N. Hasan, A. Islam, S.H. Teo, M.M. Hasan, M. C. Sheikh, M.R. Awual, Sustainable detection and capturing of cerium (III) using ligand embedded solid-state conjugate adsorbent, J. Mol. Liq. 338 (2021), 116667.
[316] M.M. Hasan, K.T. Kubra, M.N. Hasan, M.E. Awual, M.S. Salman, M.C. Sheikh, A. I. Rehan, A.I. Rasee, R.M. Waliullah, M.S. Islam, Sustainable ligand-modified based composite material for the selective and effective cadmium (II) capturing from wastewater, J. Mol. Liq. 371 (2023), 121125.
[317] M.R. Awual, Efficient phosphate removal from water for controlling eutrophication using novel composite adsorbent, J. Clean. Prod. 228 (2019) 1311–1319.
[318] J. Rajesh Banu, J. Merrylin, S. Kavitha, R. Yukesh Kannah, P. Selvakumar, S. Gopikumar, P. Sivashanmugam, K.U. Do, G. Kumar, Trends in biological nutrient removal for the treatment of low strength organic wastewaters, Curr. Pollut. Reports. 7 (2021) 1–30, https://doi.org/10.1007/s40726-020-00169-x.
[319] K. Velusamy, S. Periyasamy, P.S. Kumar, D.V.N. Vo, J. Sindhu, D. Sneka, B. Subhashini, Advanced techniques to remove phosphates and nitrates from waters: a review, Environ. Chem. Lett. 19 (2021) 3165–3180, https://doi.org/10.1007/s10311-021-01239-2.