Starch-Based Antimicrobial Materials

S. Wazed Ali, Satyaranjan Bairagi, and Sourav Banerjee

Abstract Natural nanocomposites occupy a huge arena in the developing industries related to food and medicine. Nanomaterials are mainly used to strengthen the polymer matrix and their dimensions range from 1 to 100 nm. They also enhance the mechanical, thermal, optical, physical and chemical features of the polymeric materials as compared to their virgin structures. Examples of different nano-based composite materials have been identified in the recent era. Out of those, starch and clay are the most common ones. Other natural materials like chitosan, agar, proteins and their blends are also recognised by the researchers. Nano-based composites, offering antimicrobial properties, have been studied extensively in the recent past due to its applications in food packaging industry, so that the packages can be hygienic in nature and prevent the growth of bacteria causing food borne diseases such as *Staphylococcus aureus* (Gram-positive) and *Escherichia coli* (Gram-negative), etc. However, it has limitations like when food is packed in such packages containing such preventive film, needs a high content of the antimicrobial material in the film that leads to the enhancement of the food shelf period and thus there is a scarcity of the main antimicrobial agents. The use of various starch incorporated antimicrobial films can reduce this imitation. This chapter mainly deals with the evaluation of the antimicrobial properties of different starch-based materials containing different nanocomposite films, which have their wide range of applications in the field of biomedicines and food packaging.

Keywords Starch · Antibacterial · Packaging · Nanocomposite

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1 Introduction

As per the reported literature by Parra et al. (2004) almost 150 million tons of synthetic polymeric materials are produced in a year all over the world. The extensive production of synthetic polymeric materials leads to their increase in consumption. These synthetic polymers are generally obtained from petroleum based products. In last few decades, chemically developed synthetic polymers have been used extensively in different applications specifically in food packaging industry. These synthetic polymers are not eco-friendly as well as non-biodegradable which causes environmental pollution and serious health issues to the human beings (Chen et al. 2013). For mitigating problems associated with the synthetic polymers, present generation has tried to find alternative pollution-free and bio-degradable materials. There are different natural polymers which are eco-friendly and bio-degradable in nature and possess easy process ability. For instance, the natural sources can be enlisted as chitin, chitosan, cellulose, protein, lipids, gum and starch-based polysaccharides. Among these starches have drawn a great interest in the different applications due to its large amount of availability, low cost, non-allergic and thermo-processability (Salleh and Muhamad 2010; Bum n.d.). Starch is a biopolymer originated from agricultural sources. Due to the above-mentioned advantages of starch, recently, researchers have tried to develop starch-based materials targeted for manifold industrial applications like in biomedical industries. However, starch has limitations such as lower mechanical properties and higher hydrophilicity. Due to hydrophilic characteristics of starch, it has lower moisture barrier capacity. In order to improve the physical and functional properties of the starch-based biopolymers, other biopolymers have been added with them. For example, chitosan has been blended with the starch to impart their physical and antibacterial properties as chitosan is a good antibacterial natural polymer (Bangyekan et al. 2006). Also, the use of sliver nanoparticles incorporated in starch to produce starch/silver nano-capsules has been reported by a method called addition polymerisation. A very less concentration of such prepared starch-based nano-capsules obstructs the bacterial (*Staphylococcus epidermidis* and *Escherichia coli*) growth (Taheri et al. 2014). Furthermore, the use of both the chitosan and sliver nanoparticles in starch has been illustrated wherein chitosan has been used to reduce sliver nitrate. It has also been observed that starch promotes no antimicrobial properties but when incorporated with chitosan and sliver the composite material shows very effective antimicrobial effect. The inhibition zone of starch-chitosan based film as reported is 28 mm whereas for starch-chitosan-sliver based film is more than 30 mm against *S. aureus*, *B. cereus*, and *E. coli* bacteria (Yoksan and Chirachanchai 2010).

The present chapter is a latest and brief composition of starch-based antimicrobial materials which have promising applications in various segments, especially for packaging food materials and medicines.

2 Source and Structure of Starch

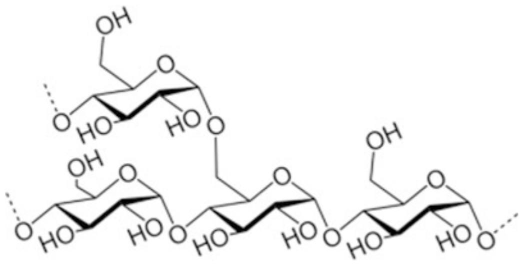
Starch can be obtained in granular form and is found in roots, seeds, stems, and tubers of various plants, like corn, potato, wheat, rice, sago, etc. Starch is made up of anhydro-glucose chains that lead to the formation of two polymers named as amylose and amylopectin. Out of these two polymers, amylose can be found as a well-ordered polymer chain containing 20–30% of starch in granular form. It is available in long chains containing α-(1,4)-linked D-glucose. The other polymer unit amylopectin is a randomly structured polymer including 70–80% of the starch granules. It contains α-(1,4)-linked glucose molecular units, linked with-(1,6)-unit (Torres et al. 2013). As an example, the structure of starch obtained from corn extract is shown in Fig. 1.

3 Antimicrobial Property of Starch-Based Materials

The problems witnessed by using synthetic materials in food packaging lead to pollution in the environment. So, to mitigate the shortcomings various natural polymers have been explored that can be effectively used in packaging industries. Out of various natural polymers identified so far starch is being renowned as the most important one due to its biodegradability, biocompatibility, edible and sustainable properties. But starch has different limitations to be used for food packaging due to its reduced mechanical, barrier and processing characteristics. Therefore, to overcome all such limitations starch is being blended with different natural polymeric materials and their derivatives like carboxy methyl cellulose (CMC), chitosan or by using different nanocomposite based materials consist of nanoparticles of silver, zinc oxide, etc. There are many approaches as explored by the researchers to enhance the properties of starch. Inclusion of starch as nanocomposite film is one so that it can be successfully used in the food industry (Hu et al. 2019).

Ashjari et al. have reported an innovative approach to develop starch-based polyurethane incorporated copper oxide nanocomposite foam to minimise bacterial growth. They have observed that such a fabricated composite shows a promising antimicrobial effect when used in a hospital mattress. They found that copper oxide nanoparticles when synthesised by thermal degradation method at a temperature of

Fig. 1 Structure of starch extracted from corn (Spiridon et al. 2019)



600 °C shows bacterial inhibition against a range of bacteria like *S. aureus*, *E. coli*, *P. aeruginosa*, *E. faecalis and C. albicans.* In this case, copper oxide nanoparticles release Cu^{2+} and show electrostatic interactions between Cu ions and the bacterial membrane which results in rupture of the plasma membrane of the bacteria (Ashjari et al. 2018; Yadav et al. 2017).

Chen et al. have developed an antibacterial film based on tapioca starch/decolorised Hsian-Tsao leaf gum and evaluated its antibacterial activity against *Listeria monocytogenes*. To extract the herb the researchers have used potassium sorbate and thyme. Extracted gum showed a rough texture when potassium sorbate was used whereas, a smooth texture was found when thyme was used. Antimicrobial efficacy of starch along with decolorised Hsian-Tsao leaf gum against *L. monocytogenes* was also revealed. It has also been proved that thyme suspensions show an inhibition zone of diameter ranging from 16 to 19 mm against the above-stated bacteria. On the other hand, as illustrated in the study, potassium sorbate suspension (20%) shows much less microbial obstruction property (a lesser inhibition zone of 10.7–9.7 mm). Therefore, it can be concluded that thyme solution shows better antimicrobial activity when compared to potassium sorbate solution. Antimicrobial activity of potassium sorbate and thyme in film form in combination with starch has also been evaluated. Antimicrobial activity of thyme (with a concentration of 10% showed an inhibition zone of 9 mm) film based material is lower as compared to pure thyme antimicrobial solution (inhibition zone ranging from 16 to 19 mm) due to lower interaction of the active ingredients with bacterial cells as compared to solution (which migrates fast) (Chen et al. 2013).

Vásconez et al. (2009) have studied the antibacterial activity of chitosan and tapioca starch-based film. Potassium sorbate was used with the solution of starch and chitosan coating solution to impart effective antibacterial property of the same. The authors have observed that when chitosan was used as a solution form, antibacterial activity in terms of reduction of bacteria population (*Lactobacillus* spp.) was higher due to direct contact of chitosan biomolecules with the bacteria. Whereas, chitosan in the form of starch/chitosan film shows a lower antibacterial action against *Lactobacillus* spp. This is due to entrapment of antimicrobial chitosan biomolecules firmly in the starch/chitosan film and this the solid form of chitosan in the starch/chitosan film has less chance to get interacted with the bacterial cell surface as compared to the chitosan in the form of solution. As a result the antibacterial property gets reduced.

Abreu et al. (2015) have reported antibacterial property of different starch-based nanocomposites such as starch/nanoclay, starch/silver nanoparticles and starch/nanoclay/silver nanoparticles nanocomposites against *Staphylococcus aureus*, *Escherichia coli and Candida albicans* bacteria. The pure starch-based film shows no inhibition zone against three different bacteria (*S. aureus*, *E. coli and C. albicans*) which confirms that starch has no antibacterial effect. While, starch/nanoclay-based film shows some inhibition of bacterial growth due to the presence of quaternary ammonium compound in nanoclay. However, there is no antibacterial effect of the starch/nanoclay-based film against *C. albicans* bacteria. But all the nanocomposite films based on silver nanoparticles (starch/silver nanoparticles and starch/silver nanoparticles/nanoclay-based nanocomposite films) show substantial antibacterial

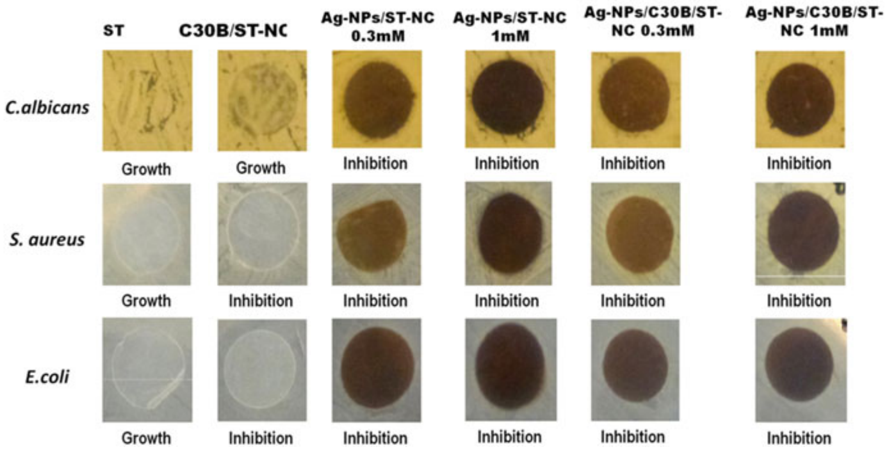


Fig. 2 Antibacterial activity of starch, nanoclay/starch, silver nanoparticles/starch and silver nanoparticles/nanoclay/starch-based nanocomposite films against bacteria of *C. albicans*, *S. aureus* and *E. coli* (Abreu et al. 2015)

action as compared to the starch/nanoclay-based film against all the tested bacteria like *S. aureus*, *E. coli and C. albicans* as shown in Fig. 2. The antibacterial action of silver nanoparticles-based film was due to the interaction of Ag^+ with marcapto group of the bacteria and its controlled release from the nanocomposite film.

In another study, Pyla et al. (2010) have developed tannic acid impregnated starch-based film and tested the antibacterial property of the film. Two differently produced films namely starch/commercially available tannic acid and starch/processed tannic acid have been used to study. It has been found that the starch/processed tannic acid-based film shows the higher inhibition area when compared to the starch/commercially available tannic acid film against *Escherichia coli O157:H7* and *Listeria monocytogenes* bacteria. This study reveals that thermally processed tannic acid is more effective than fresh tannic acid to protect the microbial growth.

Shen et al. (2010) have reported the antibacterial and physical properties of potassium sorbate or chitosan loaded sweet potato starch-based film. They have observed no antibacterial effect in the case of 10% potassium sorbate loaded starch-based films due to strong hydrogen bonding between the hydroxyl groups of starch and carbonyl groups of potassium sorbate. Whereas, antibacterial action was observed for the higher concentration (>10%) of potassium sorbate-based film against *E. coli* bacteria. Conversely, only 5% chitosan loaded starch-based film shows an effective antibacterial action against bacterial growth. This is due to protonation of NH_2 groups of chitosan into the NH_3^+ ions which can interact with the anionic group of microbial cell membranes. The antibacterial activity of potassium or chitosan loaded sweet potato starch-based films against *E. coli* and *S. aureus* bacteria is depicted in Fig. 2. They have also explained the antibacterial properties of sweet potato starch films in the form of solid and semi-solid against *E. coli* and *S. aureus* bacteria. It was found that there is no significant difference in antibacterial properties of starch films for both the forms (solid and semi-solid). From this finding it can be concluded that the sweet potato starch-based films can be used in food packaging with different water contents. But pH value has significant effects on the antimicrobial action of potassium sorbate and chitosan loaded sweet potato films. When pH value is 4.5, potassium sorbate gets converted into sorbic acid which disturbs the migration of antibacterial agents from the wet film. Whereas, NH_2 groups of the chitosan can be protonated into NH_3^+ ions at 4.5 pH which increase the solubility of chitosan in water and help for easy diffusion of antibacterial agents in wet starch-based film.

Hu et al. (2019) has reported the antibacterial property of the starch-based composite films loaded with ZnO and chitosan nanoparticles. The authors have synthesised ZnO-chitosan nanoparticles by sol-gel method. Then they have evaluated different properties such as mechanical, water vapour permeability and antibacterial properties of the developed starch-based composite films. They have found that microorganism growth was inhibited effectively in the presence of ZnO-chitosan nanoparticles in starch-based films. Antibacterial activity of the developed hybrid film in terms of inhibition area was maximum against Gram-positive (*S. aureus*) bacteria as compared to Gram-negative (*E. coli*) bacteria. They have also reported that antibacterial activity gets increased with increase in the concentration of ZnO-chitosan nanoparticles up to a certain limit after which the mechanical and barrier properties of the developed composite film get hampered. The antibacterial activity of the developed starch-based composite film can be explained by generation of higher amount of superoxide and hydroxyl anions when film is exposed to photocatalytic reaction, which are mainly responsible for killing the different microorganisms.

Clegg et al. (2019) has developed starch-based antibacterial coating by using silver and sodium bentonite as a filler material. They have studied the influence of $AgNO_3$ content along with washed bentonite (for removal of the additional salts). Further, in their studies they have reported the effect of back-exchange procedures, which gives an idea on the form of Ag emitted in the reaction. Various characterisation techniques can be used to measure the quantity of Ag existing in the reaction, which was done in this case by using X-ray fluorescence and a XRD along with TEM. To evaluate the antimicrobial features of the fabricated Ag/Na bentonite material, it was incorporated into a plasticised coating comprising starch along with clay. The developed material showed outstanding antimicrobial properties against a range of bacteria like *Escherichia coli*, *Kocuria rhizophila* and *Aspergillus niger* as shown in Fig. 3. Various concentrations of Ag/Na bentonites were taken into account. 0.03 weight of Ag/Na bentonite with a coat wide of 14 μm was the optimum concentration in this case to show best antimicrobial action.

Arezoo et al. have reported a novel approach to use sago starch, found mainly in the tropical regions, along with cinnamon essential oil and nano-based titanium dioxide. In this study, they have included various weight by weight percentages of nano-based titanium dioxide ranging from 0, 1, 2, 3 and 5 and various volume by weight percentages of cinnamon essential oil ranging from 0, 1 and 3 into the film of sago starch. Evaluations of various properties like physical, chemical, mechanical,

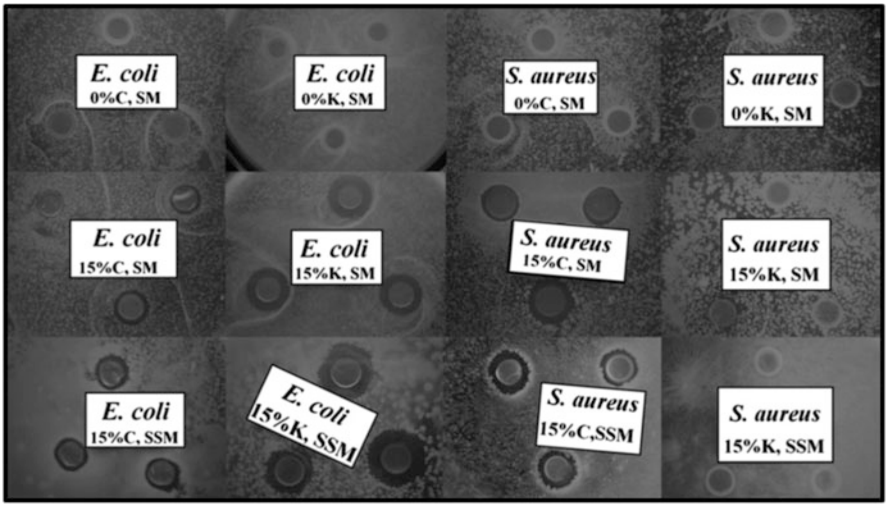


Fig. 3 Inhibition zone against *E. coli* and *S. aureus* bacteria with different concentration of potassium sorbate or chitosan incorporated starch-based films (Shen et al. 2010)

protection and most importantly antimicrobial efficacy of the nature-based nanocomposite were taken into account. The study reveals that when cinnamon essential oil was mixed in the matrix of sago starch, the increment of permeability to oxygen and water vapour was observed, whereas by the inclusion of nano-based titanium dioxide in starch matrix led to the decrement of the protection features the film. Furthermore, a decrease in moisture content was seen ranging from 12.96% to 8.04% along with a decrease in water solubility ranging from 25% to 13.7%. However, the mechanical properties of such a film was found to be more enhanced. The same starch-based film registered an outstanding antimicrobial property against different types of bacteria namely, *Escherichia coli*, *Salmonella typhimurium* and *Staphylococcus aureus*. Such nature-based nanocomposite does have its end uses in industries related to packaging of food and freshly extracted pistachio (Arezoo et al. 2019).

Spiridon et al. have explored the idea of blending various natural waste products in the matrix of starch along with poly(butylene adipate-co-terephthalate) to prepare a natural composite material. For example, by inclusion of lignin into the blended bio-composite it showed improvement in both the tensile and impact strength, whereas the rate of water absorption got reduced. Also, incorporation of lignin proved a better microbial resistant property against both the Gram-positive (*Staphylococcus aureus*) and Gram-negative bacteria (*Escherichia coli*). Such bio-composite comprising noticeable properties related to water prevention, mechanical and most importantly protection against different bacteria make the composite to have its end uses in manufacturing packages (Spiridon et al. 2019).

In a novel approach, Fang et al. prepared a bio-composite of starch film blended with salicylic acid and nanoparticles made up of maize starch along with κ-carrageenan as shown in Fig. 4a, to improve antimicrobial as well as mechanical characteristics. Such fabrication was made possible by a process of enzymolysis and re-crystallisation, along with addition of κ-carrageenan in a stepwise manner. They have also mentioned about inclusion of a filler and stabiliser in the structure of a film containing 0–9% hydroxypropyl tapioca starch. SEM images as shown in Fig. 4b–i demonstrated that such bio-composite starch-based films can have regular and even structure. The study proved that such bio-composite starch-based film can significantly improve the tensile strength, barrier to water vapour, and stability from heat. However, transparency goes down along breaking elongation, as compared to virgin starch without incorporation of any such composite materials. These bio-composites have their enormous usage in the field of food industry due to its outstanding physical, mechanical and microbial resistance properties against bacteria like *Escherichia coli*, *Staphylococcus aureus* and *Bacillus subtilis* as shown in Fig. 4 (Fang et al. 2019).

Starch included films show excellent optical, organoleptic and gas barrier characteristics, but they exhibit lower mechanical properties as studied by Thakur et al. To improve the mechanical and tensile properties of such starch-based films different natural polymers or additives can be included. It has been demonstrated by the researchers in their study that the characteristics of such film based materials can be effected by various parameters like, the type of starch, temperature, duration of film preparation, plasticisers, other natural polymers and conditions used for storage (Thakur et al. 2019).

Sen et al. in their work has proposed the idea of using a blend containing corn starch (7.50 g) as main component along with PVA (0.875 g) and glutaraldehyde (0.125 g). They have evaluated the influence of benzoic acid (BA), potassium sorbate (PS) and sodium propionate (SP) as microbial growth preventers on the different major properties such as strength, breaking elongation, permeability to water vapour and optical features. It has been justified that when 1.79 g of 100 g polymer was taken, the benzoic acid and potassium sorbate antimicrobial agents lowered the ultimate tensile strength of control film by 24.01% and 26.84%, whereas sodium propionate increased the strength by 12.35%. Furthermore, benzoic acid showed a decrease in the extent of breaking elongation by 82.82%, whereas potassium sorbate and sodium propionate showed an increase by 12.73% and 167.52%. The antimicrobial agents used in the study led to the rise in permeability to water. Considering all the results, it was concluded that sodium propionate is the best antimicrobial agent recommended due to its good water vapour permeability, which has wide applications in the field of storing fresh fruits and vegetables (Sen and Das 2019).

Pal et al. developed a new type of starch containing cations made up of N-(3-chloro-2-hydroxypropyl) trimethyl ammonium chloride along with the aid of sodium hydroxide as shown in Fig. 5a. Such prepared starch was investigated by different characterisation techniques like Fourier Transform Infrared Spectroscopy as demonstrated in Fig. 5b and also by measuring its viscosity. The flocculation property of the starch was tested by using silica suspension. It has been observed that

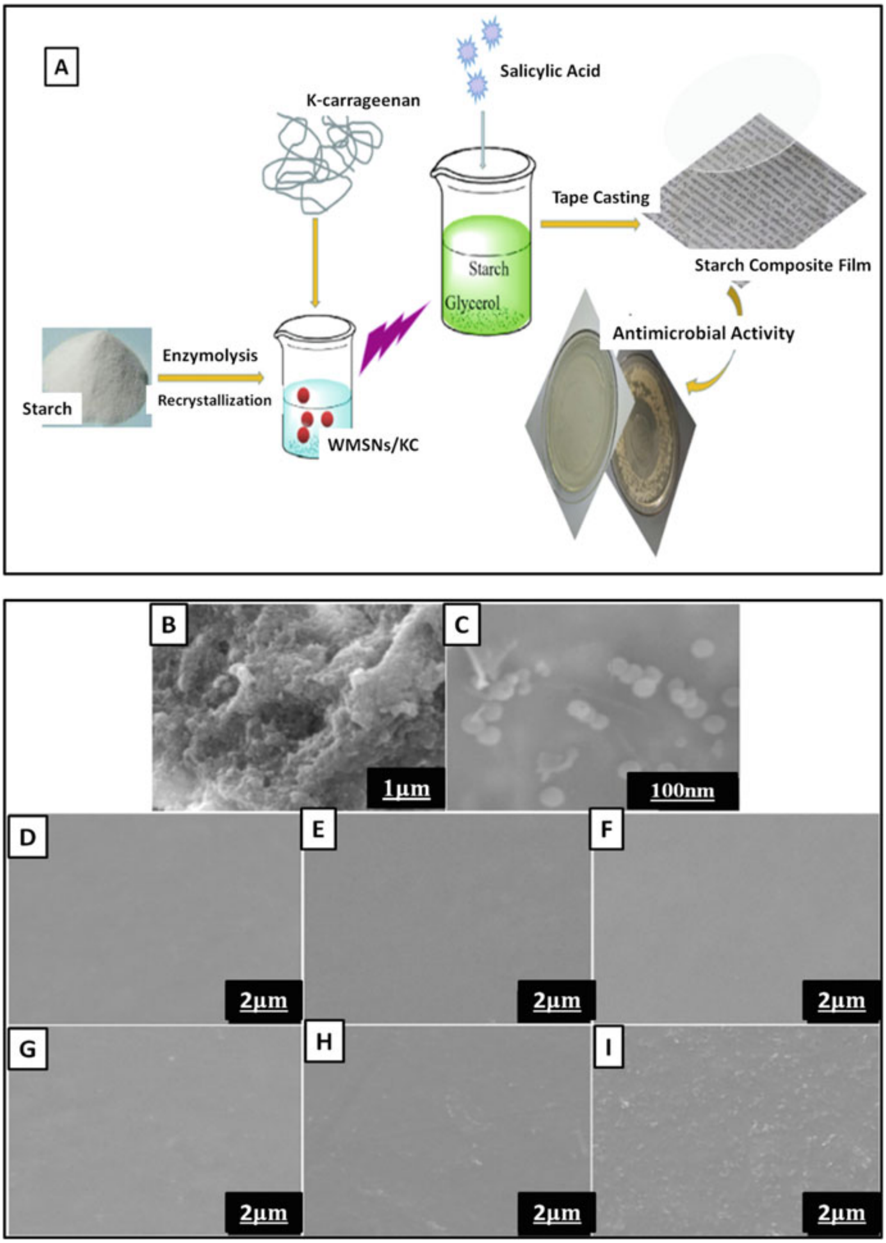


Fig. 4 (**a**) Preparation of starch based nanocomposite film, Scanning Electron Microscope pictures of composites at different magnification ranging from (**b**) 5000 to (**c**) 12,000 along with surface morphology of the film containing different concentration of composites ranging from (**d**) 0%, (**e**) 1, (**f**) 3%, (**g**) 5%, (**h**) 7% and (**i**) 9% at a magnification range of 4000 (Fang et al. 2019)

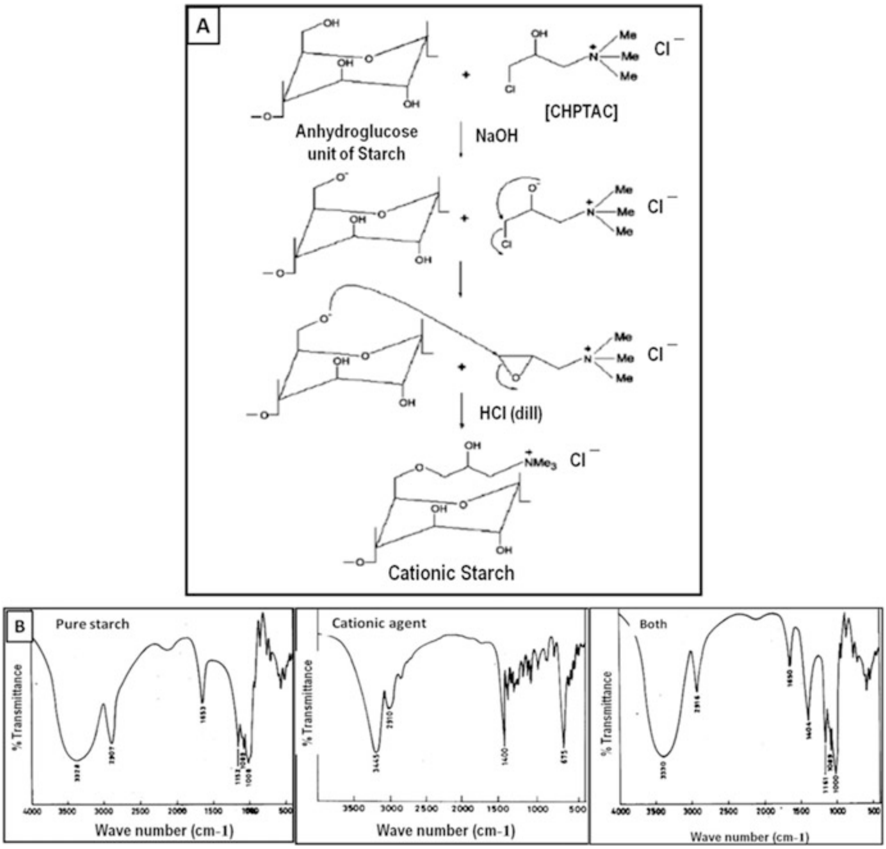


Fig. 5 (**a**) Preparation of starch made up of cationic agent, (**b**) Fourier Transform Infrared Spectroscopy of pure starch, cationic agent (N-(3-chloro2-hydroxypropyl) trimethyl ammonium chloride) and starch incorporated with above-stated cationic agent (Pal et al. 2005)

the starch with longer chain length shows the better flocculation property when compared with the starch having shorter chain length (Pal et al. 2005).

Guan et al. have reported the use of guanidine polymer in the structure of starch extracted from potato by the process of coupling to imbue the antimicrobial property. The guanidine modified starch showed good antibacterial activity against both the Gram-negative (*E. coli*) and Gram-positive (*S. aureus*) bacteria tested in shaking flask and diffusion method (Guan et al. 2008).

Effective cationisation of starch with the aid of glycidyl trimethyl ammonium chloride and maintaining the reaction parameters like catalyst concentration (NaOH), temperature along with the components used in the reaction were studied by Kavaliauskaite et al. They have stated that cationisation of starch at a low temperature has enhanced efficiency as energy required for activation of the reaction with glycidyl trimethyl ammonium chloride is much less when compared with the side reactions taking place. The concentration of sodium hydroxide affects both the main and side reaction. Cationisation of starch takes place when the total amount of sodium hydroxide available in the reaction gets adsorbed by starch in its non-solid state. The study entirely deals with the reaction factors which influence the cationisation of starch, which can be used as a promising antimicrobial agent. Such cationised starch has various other applications ranging from its usage in various industries and as a substitute which can replace the synthetic flocculants or sorbents, which has environmental pollution at an uncontrolled rate (Kavaliauskaite et al. 2008).

In a study, Salleh et al. have used lauric acid along with chitosan as an agent which prevents the growth of microbes in the structure of wheat starch. The main aim of this study was to prevent the growth of microbes in the food packages, which spoil the food stuffs. The tests were carried out against *Bacillus subtilis* and *Escherichia coli* bacteria. Both the solid media and liquid culture test methods were employed to investigate the growth of bacteria. Both the standard and antimicrobial films comprising lauric acid along with chitosan were prepared by casting process. The results from solid media test demonstrated a visible inhibition zone against *Bacillus subtilis* (Gram-positive) bacteria whereas, a much less visible inhibition zone was observed in case of *Escherichia coli* (Gram-negative bacteria). This study illustrates that starch incorporated films can contribute a major antimicrobial property to the food packaging industries (Salleh and Muhamad 2010). In another study, the use of the same material was used but in a different way, where starch and chitosan blend were used in series including lauric acid (8%). Functional groups of starch (OH groups) and chitosan (OH, NH_2 groups) can lead to a very good interaction of the two components in the blend and make the two polymers miscible. Their study revealed that the antimicrobial starch/chitosan/lauric acid incorporated film has an improved rate of transmission of water vapour and is transparent in nature with a yellowish tint with increasing content of chitosan. Such property related to water vapour of the blended film is mainly due to the hydrophobic characteristics of lauric acid. The blended film also showed an outstanding permeability to oxygen, which can enable such materials to be used in antimicrobial packaging and can be a substitute for synthetic polymers for packaging to prevent the food materials from oxidation reaction (Salleh et al. 2009).

Ali et al. reported the use of the peel extracted from pomegranate fruit as shown in Fig. 6a–c which acted as a promising antimicrobial agent along with a supporting material, to develop starch films. In this study they have incorporated water and glycerol as plasticiser into starch containing higher percentage of amylose. Both the surface characteristics and the nature of the film were evaluated by scanning electron microscope as demonstrated in Fig. 6d, e, optical microscope, X-ray diffraction, dynamic mechanical analyser, tensile testing, drop impact testing and disc diffusion test. Reports illustrated that pomegranate peel prevented the microbial growth against *S. aureus* and *Salmonella* bacteria. Pomegranate peel causes an increase in Young's modulus, tensile strength and rigidity of the starch incorporated film (Ali et al. 2019).

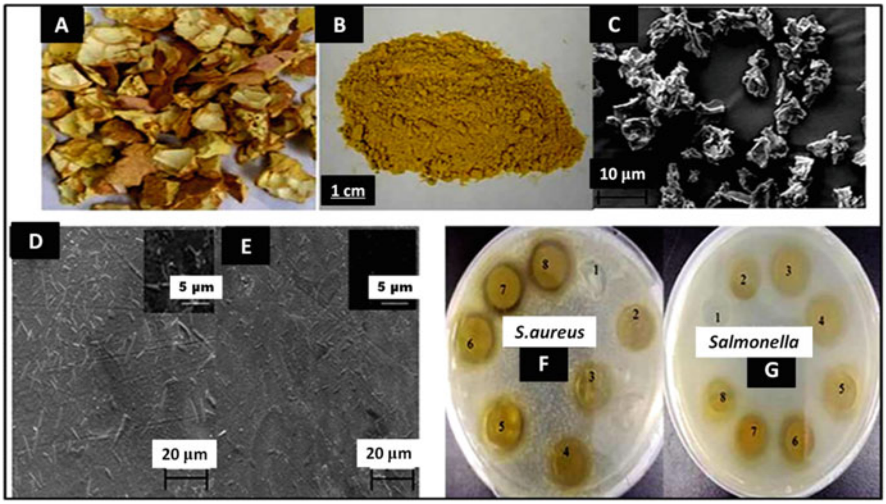


Fig. 6 Images of dried pomegranate peel in a fridge, (**a**) Granules of pomegranate peel, (**b**) Granules of pomegranate peel characterised by scanning electron microscope, (**c**) Pictures of starch based films containing pomegranate peel concentration of (**d**) 2% and (**e**) 10%, respectively. Inhibition zones of starch films with pomegranate peel against bacteria (**f**) *S. aureus* and (**g**) *Salmonella* (Ali et al. 2019)

Pelissari et al. revealed a novel approach of preparation of a film consisting of starch, chitosan incorporated with oregano essential oil. The zone of inhibition of such film was measured against a range of bacteria such as *Bacillus cereus*, *Escherichia coli*, *Salmonella enteritidis* and *Staphylococcus aureus*. Results illustrated that the film imbued with oregano essential oil effectively showed inhibition against the four above-stated bacteria along with a noticeable barrier characteristic. The existence of such oil in the film also added value to increase the elastic nature of the film. Furthermore, pure chitosan did not show much antimicrobial property against the bacteria as stated, instead the flexibility and water vapour permeability of the starch-based film get reduced. Thermal gravimetric analysis justified that no change in the stability to heat of such film was noticed by the inclusion of chitosan along with the oil. Such blended film can be a promising candidate to be used to provide resistance to bacterial growth (Pelissari et al. 2009).

Tang et al. used di-aldehyde starch, acted as a crosslinking agent, for the improvement of the mechanical property and water absorbency property of the films comprised of chitosan. FTIR and XRD showed that the crystallisation of chitosan is influenced by Schiff's base. A crosslinking content of 5% demonstrated the optimised tensile strength of 113.1 MPa and elongation at break of 27%. Such optimised chitosan-based film was observed to exhibit noteworthy antimicrobial properties against *Escherichia coli* and *Staphylococcus aureus* bacteria. These kinds of films can have their huge application in the field of biomedicines (Tang et al. 2003).

Yoksan et al. in their study has synthesised Ag nanoparticles with the incorporation of $AgNO_3$ in a solution of chitosan. Such fabricated sliver nanoparticles showed stability for a period more than 6 months. Transmission electron microscopy showed that these particles exhibited the form of a sphere having an approximate dimension ranging from 20 to 25 nm. Minimum inhibitory concentration of the fabricated material against *Escherichia coli*, *Staphylococcus aureus* and *Bacillus cereus* bacteria was noted to be 5.64 µg/mL. Solution cast procedure was used to prepare this film. Results demonstrated that inclusion of Ag nanomaterials in the structure of chitosan led to the enhancement of the tensile property, oxygen barrier property, but lowered the permeability to water or moisture. Furthermore, this specially blended chitosan-based film showed outstanding prevention against bacterial growth. This blended film can possibly have its applications in the field of packaging food and medicines (Yoksan and Chirachanchai 2010).

Jung et al. invented a novel approach of using starch-based Ag nanoparticles prepared by solution cast method in one step by ultra-sonication of the blend as described in the Fig. 7a. Here, starch was used both as an antimicrobial and reducing agent. To prepare paper that can be utilised for packaging can be obtained from the solution coated mixture of sliver nanoparticles incorporated starch. Results demonstrated that such coated films have a property of good resistance to oil along with outstanding property to prevent the microbial growth against *Escherichia coli* and *Staphylococcus aureus* bacteria as shown in Fig. 7b–d, which can find applications in food packaging, etc. (Jung et al. 2018).

Usman et al. fabricated a nanocomposite film made up of PVA, graphene oxide and Ag included in the structure of chitosan. Evaluations of various properties like mechanical, thermal and antimicrobial efficacy of the starch-based film was taken into account. The nanocomposite witnessed an enhanced tensile strength, stability to heat property by the inclusion of graphene oxide in polyvinyl alcohol. Due to the durable bonds between graphene oxide and the blended film, a thermal barrier effect was noticed. Antimicrobial properties of the prepared films were investigated against *Escherichia coli* and *Staphylococcus aureus* bacteria. Figure 8 illustrated the antimicrobial characteristics of the polyvinyl alcohol based blend of graphene oxide, sliver, graphene oxide/sliver and graphene oxide/sliver/starch (Usman et al. 2016).

Ortega et al. (2017) elaborated the use of Ag nanoparticles for studying the antimicrobial properties of corn starch-based films, used in packaging of food. The study showed Ag nanoparticles have no toxic effect on the cells. Electron microscopy analysis exhibited that the spherical shaped particles have a diameter ranging from 5 to 20 nm. Results showed that Ag nanoparticles increased the thickness of the film and it was impervious in nature. Also, with increase in the concentration of the nanoparticles, a decrease in the permeability to water was observed. Sliver nanoparticles led to the strengthening of the film along with the development of a durable and rigid material, showing an even surface as depicted in the scanning electron microscope images. Such films also exhibited the property of showing prevention against the bacteria, *E. coli* and *Salmonella* spp., which cause different food related diseases. Considering, different concentration of the sliver nanoparticles, as shown in Fig. 9a, the one containing 143 ppm of the nanoparticles

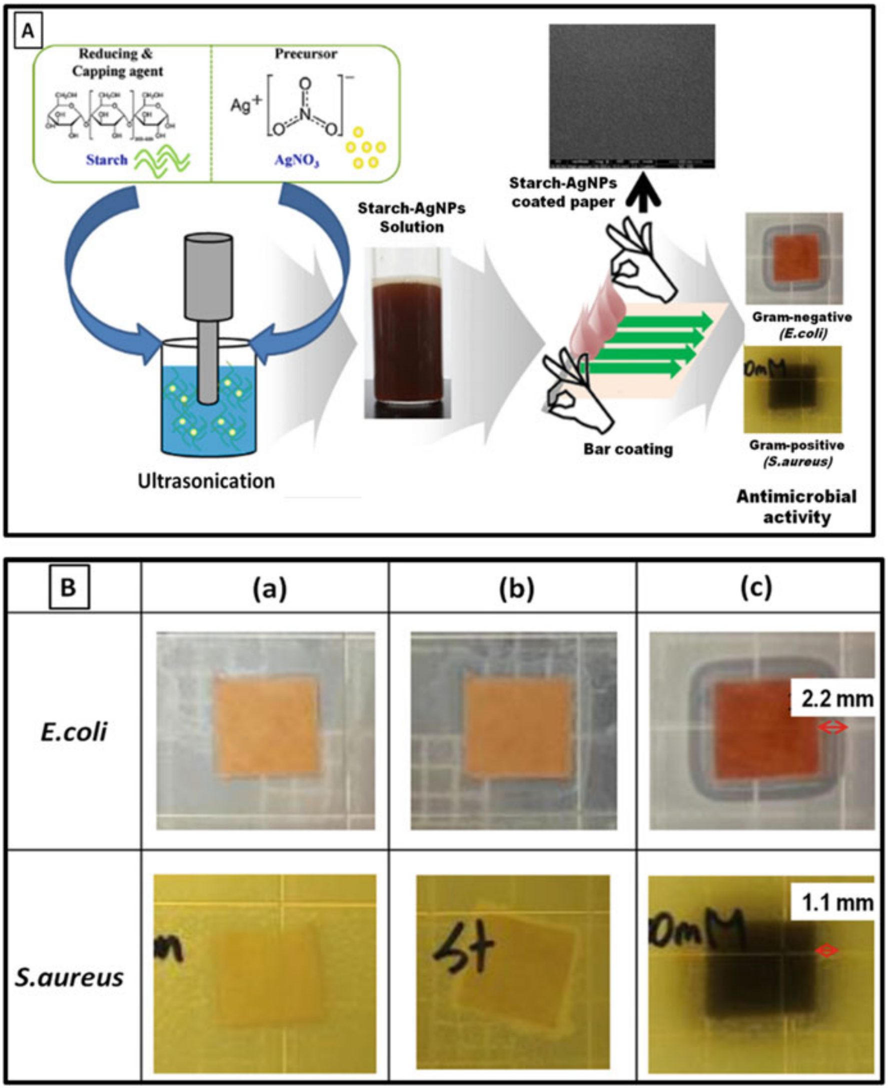


Fig. 7 (**a**) Schematic diagram showing the starch based sliver nanoparticles coated with paper along with its use in different antibacterial activities, (**b**) Pictures showing the antibacterial features of the uncoated paper (**a**), starch-coated paper (**b**), and starch based sliver coated paper (**c**) against bacteria *E. coli* and *S. aureus* (Jung et al. 2018)

was observed to show the optimised antimicrobial property. Such films were considered to keep cheese trials fresh for twenty-one days as shown in Fig. 9b (Ortega et al. 2017).

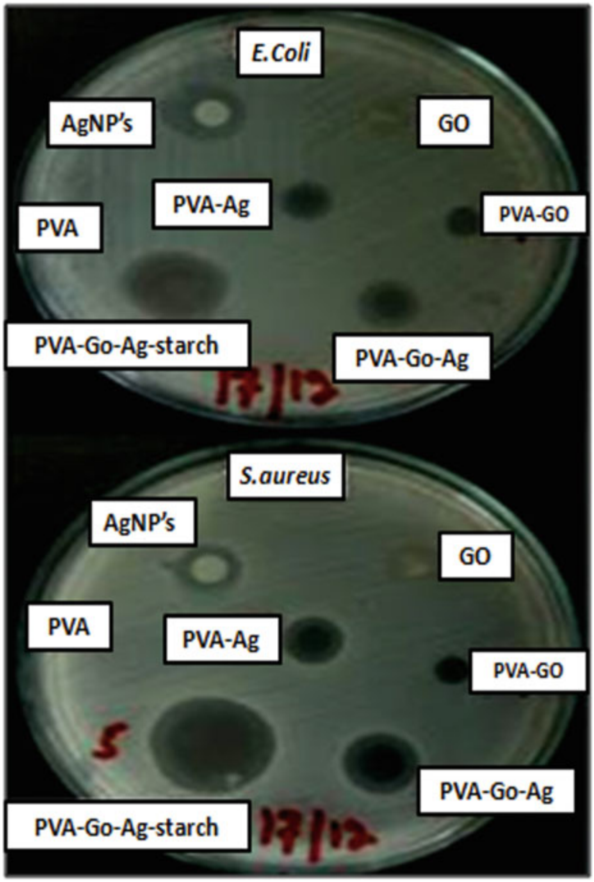


Fig. 8 Picture depicting the resistance of composite polymer film to bacterial growth against *E. coli* and *S. aureus* bacteria (Usman et al. 2016)

4 Summary

The recent statistics show that the consumption of food along with its production occupies 9 GJ of energy/year. Therefore, it is very important for us to lessen the wastage of food. After, keeping the food products for a longer period of time the growth of fungi and bacteria prevails. So, it is very essential to prevent such bacterial growth in the food products along with the packages in which they are stored. Starch, as stated by the researchers, has gained much attention for food packaging due to its biodegradability, biocompatibility, easy availability, and certainly it is cheaper. But it has limitations like it is hydrophilic in nature, prone to bacterial growth and brittle in nature. Different plasticisers are used to blend with starch to get rid of this brittleness. Still they are not suitable for its practical applications as it lags in mechanical features. Inclusion of various nano-based materials like clay, zinc oxide, titanium dioxide and magnesium oxide can improve the bacterial barrier, physical, chemical, mechanical and heat stability of starch. TiO_2 has been widely

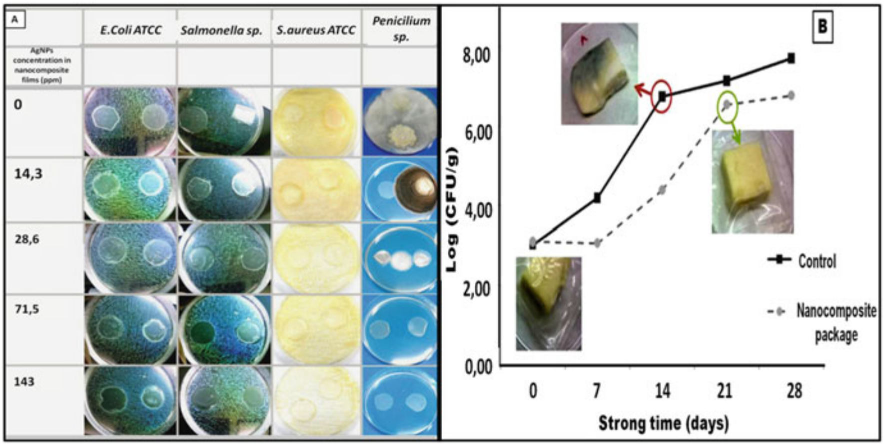


Fig. 9 (**a**) Minimum inhibitory concentration zone of sliver nanoparticles included in corn starch against bacteria *E. coli*, *Salmonella* spp., *S. aureus* and *Penicillium* spp., (**b**) Image demonstrating the influence on the shelf period of cheese trials kept in the composite film at a temperature of 4 °C (Ortega et al. 2017)

used in food and bio-medicine application due to its property to absorb ultra-violet rays and has ability to keep the food products fresh and hygienic. Nano-sized titanium dioxide prevents the growth of bacteria like *Escherichia coli* and *Staphylococcus aureus*. This material is basically synthetic in origin and offers various environmental pollution issues. So, to overcome the usage of such synthetic antimicrobial agents, use of different nature-based materials have huge scope to replace the ill effects of the synthetic category. For example, oils extracted from plants provide good and safe antimicrobial properties. Such natural materials have other properties too like it prevents oxygen gas permeability, that inhibits the growth of bacteria. For example, cinnamon essential oil is being used to pack bread and other food products. Also, such cinnamon essential oil improves antioxidant, antimicrobial, mechanical and physical features of starch-based chitosan nanocomposite materials. Therefore, it can be concluded from this chapter that different starch-based nanocomposite material, which are available in nature, can be a promising candidate in the field of food packaging and bio-medicine industries.

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