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A review on nanocomposite materials for food packaging which comprising antimicrobial activity

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Abstract
Maintaining the quality of food products during its shelf life is a prominent problem in food industry. Incorporation of nanoparticles in food packaging is a novel technique which uses in the industry to enhance its mechanical and barrier properties. Further, these polymers are biodegradable thus depicts eco-friendliness than most of conventional food packaging materials which made out of fossil and fuel. This article reviews different nanoparticles which can be incorporated in to synthetic and biological polymers, methods of synthesizing and their antimicrobial activity towards foods. Moreover, nanocomposites films which can be used in food packaging industry and the mode of improving antimicrobial activity are emphasized.

Keywords: nanoparticles, antimicrobial, food packaging, polymers

1. Introduction

The use of suitable packaging materials for food products is upcoming trend in the food industry in order to protect the quality and the freshness. Nowadays, this has become a vital important factor in food industry. Most of materials used in the packaging are produced from fossil fuels and most of them are un-degradable. Therefore people put their effort to maintain the product quality and extend the shelf life while reducing the impact of un-degradable packaging substances [1]. This has been encouraged people to explore and to develop bio-degradable packaging materials for food products.

Biodegradable or biopolymers replace un-degradable packaging materials due to their eco-friendliness. These polymers have a primary degradation mechanism and they degraded through the action of metabolism by microorganisms. Biopolymers are consist of monomeric units which are covalently bonded. The most ordinary types of biopolymers for food packaging are starch, cellulose, chitosan and agar which are derived from carbohydrates and as well as gelatin, gluten, alginate, whey protein and collagen which are derived from protein [2]. With compared to their chemical structure there are aliphatic polyesters which belong to biopolymers and they are Polylactic acid (PLA) and Polyhidroxybutyrate (PHB). These polymers comprise of different properties such as thermal stability, flexibility, barrier properties with respect to air and water, resistant to chemicals, biocompatibility and etc. But these biopolymers can degrade or transform under different environmental conditions and from microbial attack [3]. Biopolymers are limited in use for food packaging due to poor barrier properties and weak mechanical properties. Therefore natural polymers are blended with synthetic polymers which layered silicates are dispersed at a nanomeric level in a polymeric matrix [1]. Because of these reasons nanotechnology has been applied for food packaging as an emerging technology.

Application of nanotechnology for food packaging has major advantages which include enhanced barrier properties, enhanced heat-resistant properties, biodegradability and enhanced antimicrobial effects. Nanocomposites is an important alternative for conventional packaging. These are polymer matrices reinforced in the nanofillers (nanoclays, nanooxides, carbon nanotubes and cellulose microfibrils) where one of the phases has at least one, two or three dimensions less than 100 nm [4]. Usually low amount of fillers (<5%) is acceptable to gain an improvement in the properties of biopolymers. Studies has proved that the tensile strength and modulus of material increase while elongation at break decrease as the content of nanofiller increases. Apart from that higher ratios of nanofillers exhibit high tendencies towards filler incorporation thus improves barrier properties [2].

2. Common methods of synthesizing nanomaterials

2.1 Hydrothermal synthesis

Hydrothermal synthesis is known as crystal synthesis or crystal growth under high temperature and high pressure water conditions from substances which are insoluble in ordinary temperature and pressure. These are conducted in closed vessels while reactants are either dissolved or suspended in a known amount of water which is transferred to acid digestion reactors or autoclaves. There are different types of hydrothermal synthesis and they are batch reaction system and flow reaction system [5, 6].

2.2 Sol-gel synthesis

In this method a "sol" suspension is prepared and then subsequently converted in to viscous gels and solids through hydrolysation, condensation and polymerization. The nature of alkyl group, concentration of precursors, temperature, water to alkoxide molar ratio and acid or base catalyst can affect the size of nanoparticle. Faster nucleation and growth and high purity are advantages while the high cost is the disadvantage of this method [7]. The sol-gel method can cause agglomeration of MgO nanoparticles which restricts its wide application. Surfactant-mediated synthesis method is required to overcome this problem [8].

2.3 Mechano-chemical method

This is a novel method and widely applies to synthesis ZnS, CdS, ZnO, SiO2 and CeO2. The particle size depends on milling time and heat temperature. In this method precursors or salts and carbonate salts are simultaneously milled to produce carbonate of particular cation through chemical exchange reaction. Afterwards nanoparticles are obtained through calcinations. As an example crystalline ZnO nanoparticles are synthesized by milling Zinc chloride and Sodium carbonate simultaneously to produce Zinc carbonate and Sodium chloride in a ball mill. The ball mill acts as a low temperature chemical reactor and the nanostructured product mix is then heated to decompose in to Sodium chloride and Zinc oxide. Then this is wash to separate two products and then dry to obtain ZnO nanoparticles [7, 9].

2.4 Chemical vapor deposition (CVD) and chemical vapor condensation (CVC)

A solid is deposited on a heated surface via a chemical reaction from the vapor phase in CVD method while in CVC pyrolysis of vapors of metal organic precursors in a reduced pressure and metalorganic precursor is introduced in the hot zone of the reactor. For instance hexamethyldisilazane is used to produce powder by CVC technique. In thermal CVD the reaction is activated by heat while in plasma CVD, laser CVD and photo-laser CVD activate the reaction by plasma at higher temperature, laser thermal energy and ultraviolet radiation respectively [10].

3. Antimicrobial activity in different nanocomposite materials for food packaging

Antimicrobial nanomaterials denote for active packaging concept and the main reason for the effectivity is the high surface to volume ratio and enhanced surface reactivity of the nanosized antimicrobial agents. Most of antimicrobial nanocomposites are synthesized including metal ions such as silver, copper, gold and platinum and metal oxides such as titanium dioxide, zinc oxide and magnesium oxide. Apart from them organically modified nanoclays can be incorporated [11]. These metallic oxides are used as photocatalysts and these are irradiated with ultraviolet radiation to synthesize highly reactive oxygen species which can lead to conduct antimicrobial activity [12]. Photocatalytic semiconductor oxides can be applied for food packaging to reduce biological risks. Titanium dioxide is such photocatalytic semiconductor which denotes strong properties, safety and long term physiochemical stability. This has self-cleaning, self-disinfecting properties and it has the ability to inactive a wide spectrum of microorganisms [13].

Silver nanoparticles are incorporated into thermoplastic packaging materials such as Polyethylene (PE), Polypropylene (PP), Polystyrene (PS) and nylon. Researchers have found out that colloidal silver particles can exhibit excellent antimicrobial activity against *E.coli* and *S.aureus*. Further, silver nanoparticles can be incorporated into biopolymers such as alginate, chitosan and starch which depict a high antimicrobial activity towards Gram-positive and Gram-negative bacteria [14]. Cellulose based absorbents is a carrier for silver nanoparticles and studies have found out that total aerobic bacteria count was significantly reduced while lactic acid bacteria was less sensitive and *Pseudomonas* spp. And *Enterobacteriaceae* counts were below than control samples. Moreover, nanostructured starch based film containing clay and silver nanoparticles improve mechanical and gas barrier properties with good antimicrobial properties due to complexation between silver nanoparticles and large number of hydroxyl groups [15].

Copper nanoparticles are useful in various fields including food processing, biomedical equipment and devices and water treatment. It has been identified that copper nanoparticles have antibacterial effects comparable to silver nanoparticles. Copper based composites can be synthesized form both synthetic and natural biopolymers such as cellulose, starch and chitosan. Studies have been conducted for cellulose matrices which copper nanoparticles were incorporated. It revealed that they depicted an antibacterial action against *K.pneumoniae* prominently [16]. Apart from that nanocomposites incorporated with copper nanoparticles depict antifungal properties also. But copper is not generally used in food packaging industry as it is a toxic due to acceleration of biochemical deterioration with foods by chemical oxidation [12].

Among metal oxides nanoparticles, TiO_2 is a vital important material which has antimicrobial properties. Microorganisms can be killed by TiO_2 (Titanium dioxide) upon illumination of light. Hydroxyl radicals and reactive oxygen species generate on illuminated TiO_2 surface and they can oxidize the polyunsaturated phospholipid components of the cell membrane of microbes. Therefore TiO_2 nanoparticles can be incorporated in to food packaging to enhance its antimicrobial properties [17]. TiO_2 incorporated packaging materials possess activity against food-born microorganisms as well as odor, staining, deterioration and allergens. But there are some practical issues regarding TiO_2 nanoparticles because the photon utilization efficiency is low and it needs ultraviolet radiation as an excitation source [12].

Zinc oxide (ZnO) nanoparticles can be incorporated in to different materials such as low density polyethylene (LDPE), polypropylene (PP), polyurethane (PU), paper and chitosan. Among metal oxides zinc oxide nanoparticles are considered as safe materials for human beings than other metal oxides. Studies have found out that glass incorporated with ZnO nanoparticles depicted antimicrobial activity against *E.coli* and *S. aureus* while incorporated PU films had antimicrobial activity against *E.coli* and *B.subtilis*. Further ZnO nanorods deposited onto glass surface showed antifungal activity against *Candida albicans*. These can be incorporated to biopolymers such as chitosan in food packaging which is slightly less effective than silver nanoparticles incorporated nanocomposites but researchers had found out 99.92% of viable bacteria of *E.coli* was inactivated after 24 h incubation period. In addition this type enhanced antibacterial effect over *B.subtilis*, *Enterococcus feacalis*, *Pseudomonas aeruginosa*, *S.typhimurium* and *S.aureus*. The mechanism behind this is the distruption of bacteria cell membranes by Zn ions and oxidative stress because of photocatalytic production of reactive oxygen species [9, 18, 19].

Magnesium oxide (MgO) is known as magnesia can be used as nanofiller to improve antibacterial properties and to improve the properties of the material. Studies have been done by Sanuja S, Agalya A and Umapathy MJ in 2014 to find out the antimicrobial properties in MgO reinforced chitosan bionanocomposite incorporated with clove oil. It was found out that chitosan-MgO containing clove is an active food packaging material which possess antibacterial activity against Staphylococcus aureus [20].

4. Conclusion

Nanoparticles can be incorporated in to both natural and synthetic biopolymers in processing of food packaging materials in order to enhance its antimicrobial properties. In that nanoparticles of metal ions and as well as metal oxides can be incorporated by using different processing techniques. Thus the quality of food and freshness of food can be maintained.

5. References

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