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Sustainable Food Packaging: A Brief Review of Chitosan-Based Materials

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Abstract:

The rapid global population growth and advancing technologies have significantly increased the demand for resources, leading to environmental challenges. The packaging industry, a critical sector for protecting products and extending shelf life, has relied heavily on petroleum-based polymers. However, these non-biodegradable materials pose severe environmental and waste disposal concerns. Biodegradable polymers, particularly those derived from natural sources like chitosan, offer a promising alternative. Chitosan, derived from chitin, is a renewable, biodegradable, and non-toxic biopolymer with excellent film-forming and antimicrobial properties. When combined with other biopolymers or nanofillers, chitosan's mechanical, barrier, and antibacterial properties can be enhanced, making it an ideal candidate for sustainable food packaging. This review explores the potential of chitosan-based films, their fabrication methods, and their role in extending food shelf life while minimizing environmental impact. The article highlights recent advancements, challenges, and the future prospects of chitosan as an eco-friendly solution for food packaging applications.

Keyword: Sustainable, Packaging, Chitosan, Antimicrobial, Biodegradable

1. Introduction:

The demand for resources, energy, food, and water has exploded in the twenty-first century, owing to a growing global population, and quickly evolving technologies. To create the needed materials, society could try to rely more heavily on renewable resources, such as biomass. Sustainable development necessitates the development of products that are manufactured from renewable resources, are ecologically benign, do not include petroleum, have minimal health and safety issues, and are commercially viable. The synthesis of fine chemicals and functional materials from natural resources is of tremendous public benefit, given the growing environmental and ecological concerns caused by the usage of petroleum-based chemicals and products.

Nowadays, the packaging business is critical not only for protecting and preserving products from manufacturing to consumption, but also for providing information on product quality and, in the case of active packaging, for interacting with the product and extending its shelf life. It is critical in making food manufactured in one location available to consumers in another location after days, weeks, or even months have passed after the initial harvest or production. Nomadic humans used to gather food only when it was time to eat it. It became vital to preserve food for future use as the demand for dwellings and shelters grew, as did agricultural development. That's when the need for storing and packaging became apparent. Leaves, shells, woven grasses, hollowed wood, animal organs, and other items were used for this purpose *(Berger, 2002).* As a result, packaging accounts for around 2% of the gross national product (GNP) in developed countries, making it the world's third largest industry. Packaging must be made from certain materials in precise forms and textures, scientifically engineered to suit the product being packaged, reduce vulnerabilities during transit and storage, extend the product's shelf life, and ultimately influence the consumer's decision.

Food packaging is designed to protect food from physical and chemical pollutants, microbial contamination, and loss of fragrance while preserving the product's quality over a prolonged shelf life *(Robertson, G., 2006).* To address the identified concerns, packaging must operate as a gaseous barrier, preventing moisture, carbon dioxide, oxygen, and aromatics from escaping while maintaining appropriate optical, physical, and mechanical qualities. Petroleum-based polymers provided a traditional answer to the aforementioned questions. The manufacture and usage of nonbiodegradable materials or plastics for food packaging has expanded dramatically in recent years.

However, petroleum-based polymers used in food packaging are nonbiodegradable, non-renewable, and non-compostable, posing a huge environmental and disposal concern as well as waste generating difficulties around the world. Packaging waste amounted for 71.6 million tonnes, or 29.5 percent, of total municipal solid waste (MSW) in the United States in 2009 *(www.epa.gov)* and 56.3 million tons or 25% of the MSW in 2006 in Europe, *(www.wastemanagement-world.com)* according to statistics *(Valdés, A. 2014).* The hunt for biodegradable polymers (biopolymers)-based alternatives to petroleum-based polymers is fuelled by growing environmental concerns and a limited number of disposal options.

A rising number of studies have been focused on the development of food packaging materials that may rapidly breakdown and entirely mineralize in the environment, in order to fulfil the growing demand for sustainability and environmental safety *(Rhim, J.W. 2013).*

In comparison to synthetic polymers, natural biopolymers have the advantages of being biodegradable, renewable, and edible. Proteins such as soy protein isolate, wheat protein isolate, maize zein, wheat gluten, and gelatin are examples of biodegradable polymers, while carbohydrates include starch cellulose, chitosan, and agar *(Rhim et al., 2013, Rhim et al., 2007).*

Synthetic biopolymers include polylactic acid, polycaprolactone, and polyvinyl alcohol, to name a few. Polyhydroxybutyrate (PHB) is a microbial polyester biopolymer, whereas pullulan and curdlan are carbohydrates. However, when used alone, polymers have weak tensile, mechanical, and barrier qualities, resulting in their failure as robust and effective packing materials. Polymers also fall short of meeting the rising demands and expectations of today's consumers. Polymers are reinforced with nanofillers that interact at various levels to improve their mechanical and barrier properties and to impart unique qualities.

2. Chitosan as a promising candidate

Exoskeletons of crustaceans and insects, as well as the cell walls of fungus and yeast, include chitin. Chitin, like cellulose in plant cells, functions as a structural substance. It is a polymer made up primarily of (1-4)-linked 2-acetamido-2-deoxy-D-glucose monomers that is generated in massive quantities, with 10^{11} metric tonnes produced per year *(Elieh-Ali-Komi & Hamblin,2016).*

It is the most abundant biopolymer of animal origin and the second most abundant biopolymer on the planet after cellulose. Because of its nitrogen content, it differs from other polysaccharides. Chitosan is a deacetylated chitin derivative made up primarily of (1-4)-linked 2-amino-2-deoxy-D-glucose monomers. Chitosan (CS), a linear and partially acetylated (1–4)-2-amino-2-deoxy-b-D-glucan derived from chitin, is the world's second most abundant natural polymer *(Muzzarelli et,al.2012, Azeez et,al.2013).* It is a linear amino polysaccharide that contains D-glucosamine and N-acetyl-D-glucosamine units and is derived from chitin after deacetylation. Chitosan has been used in a variety of industries, including medicine, agriculture, food, textiles, the environment, and bioengineering, due to its antibacterial activity, nontoxicity, biocompatibility, biodegradability, chelating ability, and other characteristics.

Deacetylation of chitin is the most common and cost-effective method for isolating chitosan. Film formation is regarded the most important attribute of chitosan, which has been thoroughly investigated by various experts, especially in the context of food packaging *(Rodrigues, C.2020, Ahmad, M.2016, Ruchir Priyadarshi,2020).*

The capacity of the films to improve food quality has been investigated, which is attributed not only to chitosan's barrier qualities but also to its inherent antibacterial activity. Fabrication of pure chitosan or chitosan blend films, membranes, and edible coatings has studied by many researchers. Chitosan is perhaps the only natural polysaccharide that shows antimicrobial activity against bacteria, fungi, and yeast. Its antimicrobial activity depends on its cationic nature, concentration, the period of exposure, and the test organism. For food packaging applications, the chitosan can be used either in the form of packaging films or coatings directly on food material. Depending on the final application in food packaging, various methods for film fabrication have been developed. The current fabrication techniques for chitosan films include direct casting *(Sakurai, K. 1984, Shankar, S.2018, Yadav, M.2020*), Coating *(El Ghaouth, A.1991, Fang, Z. 2018, Ortiz-Duarte, G. 2019)*, layer-by-layer assembly *(Li, F.2013,* *Xiao, W. 2013)* and extrusion *(Steckel, H.2004, Martinez, 2014).* The methods can be used for neat chitosan films without any other polymers, or the chitosan films blended with other polymers. Several researchers have manufactured and studied neat chitosan films without the use of any additional polymer using chitosan for packaging purposes. Other substances, such as dilute acids, plasticizers, and emulsifiers, facilitate in the creation of these films. Despite the fact that pure chitosan films have food packaging properties, they lag significantly behind synthetic polymeric films and are hence inadequate for mass use in food packing.

3. Improvement of chitosan film packaging ability

Several studies have been published on chitosan films including various polymers such as polysaccharides, proteins, synthetic polymers, and so on. Chitosan's properties are improved by combining it with polysaccharides. Starch has excellent film-forming characteristics, and when combined with chitosan, the resulting film improves water barrier properties while also increasing antioxidant and antibacterial activity *(Alix et al., 2013; Talón et al., 2017; Woranuch & Yoksan,2013).* The shelf life of cheese and wheat bread was successfully extended using chitosan cellulose blend films with increased mechanical properties *(Noshirvani, Ghanbarzadeh,2017; Youssef,2016).* Other cellulosic materials, such as methylcellulose, hydroxypropyl methylcellulose, quaternized hemicellulose, and micro fibrillated cellulose, have been combined with chitosan to create composite films *(Chen et al., 2016; Gol et al., 2013).* High moisture resistance, transparency, elasticity, and other properties were found in the films, which are crucial in the food packaging environment.

Several researchers have reported mixing chitosan with synthetic polymers in addition to other biopolymers. Although the resulting polymer isn't totally biodegradable, combining chitosan with synthetic polymers can help hard-to-degrade plastics disintegrate faster. One of the most widely utilised synthetic polymers combined with chitosan is polyvinyl alcohol (PVA), which is non-toxic and water-soluble. The blend films not only have better mechanical qualities, but they also have better water and oxygen barrier capabilities *(Giannakas, A. & Salmas, 2020).* Chitosan is used in the food packaging industry in the form of flexible packaging films and coatings. Unlike coatings, which are nearly always edible because they form a layer immediately on the top surface of the item, flexible films can be either edible or inedible. Several additives have been added to each form of packaging to give it different qualities *(Kim, K. M. 2016; Kerch, G. 2011).* To avoid affecting chitosan's food-grade accreditation, the edible coatings contain just the minimum necessary of additives, if any at all.

Fillers made of metal and metal oxide nanoparticles are used in food packaging polymers to improve mechanical, barrier, thermal, and photodegradation qualities. Other features pertinent to food packaging are also addressed by these nanoparticles. They have excellent antibacterial and antioxidant properties, resulting in a longer shelf life for the products. The silver nanoparticle embedded chitosan films demonstrated increased antibacterial efficacy against gram-positive bacteria S. aureus and B. subtilis, as well as gram-negative bacteria P. aeruginosa and E. coli, according to *Tripathi et al. (2011).* Zinc oxide nanoparticles were produced and employed as fillers in the chitosan matrix by *Priyadarshi and Negi (2017).* Due to chitosan and zinc oxide, the resultant films have synergistic antibacterial action against B. subtilis and E. coli. Furthermore, the reinforcing impact of zinc oxide nanoparticles has resulted in a significant increase in mechanical characteristics. *Youssef et al. (2015)* developed chitosan-silver-zinc oxide composite films that were efficient against S. aureus, E. coli, S. typhimurium, B. cereus, and L. monocytogenes.

As packaging experts' interest in active food packaging materials grows, greater emphasis is being placed on finding compounds that, in addition to improving film qualities, also impart biological activity to the films. With increased market competition to extend food shelf life while retaining environmental friendliness and economics, the development of biodegradable, biocompatible, non-toxic, and cost-effective biologically active chemicals is becoming increasingly crucial. Natural essential oils derived from renewable plant parts or agricultural wastes are proving to be a promising contender for this application. Many studies have attempted to include these essential oils into chitosan films, with the expected outcomes so far. Apart from providing antibacterial and antioxidant properties to the films, these essential oils can also provide plasticizing and water resistance, which is a significant benefit. *(Holley & Patel, 2005; Canillac & Mourey, 2001; Kanatt, Chander, & Sharma, 2008; Mari, Bertolini, & Pratella, 2003;Pessoa, Morais, Bevilaqua, & Luciano, 2002; Juglal, Govinden, & Odhav, 2002).*

To improve the mechanical properties of films, a few researchers have combined plasticizers and cross-linkers. The clean chitosan film had a tensile strength of roughly 47 MPa and a break elongation of 17%, but the crosslinked films had a tensile strength of 113 MPa and a breaking elongation of 27%, respectively. The antibacterial activity of the chitosan films was not affected by cross-linking. *Jin et al. (2004)* produced Genipin crosslinked chitosan films that had better elasticity and mechanical characteristics. The films were also insoluble in both acidic and alkaline media. In watery media, however, the films swell.

Research developments have enabled the modification of chitosan films with various additives, which not only improved the properties of the chitosan films but also provided them with a variety of capabilities. Chitosan films have demonstrated their potential to extend the shelf life of food while maintaining its quality so far. In addition, on a lab scale, the biopolymer has been used in the form of edible coatings to extend the shelf life of fresh produce or processed fruit, vegetables, poultry, and dairy items without affecting its sensory qualities. However, more efforts are still required to develop the technology.

4. Conclusion:

In conclusion, the growing environmental concerns associated with petroleum-based packaging materials underscore the urgent need for sustainable alternatives. Chitosan-based biopolymer films present a promising solution, offering biodegradable, renewable, and environmentally friendly properties that can address the challenges posed by conventional packaging materials. The incorporation of chitosan with other biopolymers or nanofillers further enhances its mechanical, barrier, and antimicrobial properties, making it a viable option for food packaging applications. While significant progress has been made in developing chitosan-based films, further research is necessary to optimize their properties, scale up production, and overcome limitations such as moisture sensitivity and mechanical strength. With continued innovation and development, chitosan-based packaging could play a crucial role in reducing environmental impact, extending the shelf life of food, and promoting sustainability in the packaging industry. The future of biopolymer-based packaging appears promising, with the potential to revolutionize the way food products are packaged and preserved.

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