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Economic factors of chitosan based packaging (review)

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Abstract

The food packaging is one of the most important part of the food industry. It concerns being a preservation technology, but it is an important factor in the marketing and logistics too. Nowadays the environment sustainability of packaging concerns the most serious between more and more other features. The ideal food packaging material should keep the food safety and quality, be easy for maintenance, inexpensive, capable for recycling and biodegradable. The most commercial packaging are the polyethylene, polypropylene, polyethylene-terephthalate based composites but they are not suitable for the circular bio economy because they are petroleum based and their waste is not biodegradable. The chitosan maybe a suitable alternative for food packaging because it is derived of the chitin, which is the second most abundant biopolymer on the Earth and its characteristics concerns for versatile application in the food industry. It is commercial, capable to preserve the quality and safety of the food or their components, environment friendly and has healthy benefits. This study is a collection about the application of chitosan based multicomponent packaging materials developed in the projects of the authors collective.

Key words: environment sustainability, antimicrobial activity, antioxidant activity, quality and safety preservation, physical properties, barrier properties

Introduction

The consummation of fresh fruits and vegetables is very important part of healthy human diet. Maintenance a balanced safety nutrition is a more and more difficult task with a continuous growth of humankind (Sharma et al., 2024). More than one seventh of the food production and 12% of fruit and 25 % of vegetable production is wasted every year without arrive to the trade (do Canto et al., 2021; Chen et al., 2020; Dey et al., 2023). In prevention of a quality loss and keeping up the transportability of valuable fresh agricultural crops, the packaging plays a very important role (Nilsen-Nygaard et al., 2021), but most of the used wrapping materials mean a harmful waste after application. The most important factors of quality and safety changes of the perishable fruits and vegetables are the respiration, the moisture lost and the bacterial or fungal infections because of their very high moisture and nutrient content. To maintain the high level of sensory and nutritional quality and food safety during transport, manipulation and trade of the field production it is necessary to find natural and biodegradable packaging materials to mitigate the contamination of trash and prevent the human poisoning. One of the possible way for sustenance the appropriate level of the freshness and elimination the dangerous accumulation of the rubbish is the use of edible coating materials. The base materials of edible coatings can be extracted from the biomass waste (Dey et al., 2023). Wide literature resources and earlier publications of our team also prove lots of good example for the capability of shelf-life extension of different edible coating materials (Ncama et al., 2018; Riva et al., 2020; From the author's group: Gechev et al., 2023; Marudova et al., 2021; Marudova et al., 2024; Sabeva et al., 2024; Zhelyazkov et al., 2022; Zsivanovits et al., 2021a; Zsivanovits et al., 2021b; Zsivanovits et al., 2024). This study is an analysis of some economical factor of this preservation method.

Advantages and disadvantages of the application of the edible coatings

Although, the literature says the commercial biopolymer coating materials cannot prolong the shelf-life of the food with high durability, but they are capable to extend the storability of the perishable fruit or vegetable production. The commercial biopolymer coatings have poor mechanical and barrier properties. The limitations of commercial polymers can be improved with blending, modification, crosslinking or composition with other biomaterials (Nilsen-Nygaard et al., 2021). The advantages of the application of edible coatings against the plastic materials are edibility, biodegradability, absence of litter, capability of carrying bioactive components and improving the health benefits of the fresh fruits and vegetables (Yadav et al., 2022). Therefore, the utilization of the foodstuff by-products to the development of edible coatings facilitate the cost efficacy and commercialization of it (Yadav et al., 2023). The intact fruits and vegetables have an external wax layer, like a natural edible coating (Firdous et al., 2023). The effects of it can be improved with different polymer and/or plant extract components or layers. The minimal processing (fresh-cut technologies, peeling, slicing, pitting) increases the injured surfaces and make more difficult to handle cleanness and safe (microbe-free) the commodities (Fan et al., 2022). The edible coating forms a thin layer on the superficies of the hurt cells, above the stomas which lead to reduce the respiration and water evaporation, retards the utilization of the fruit acids (Tiwari et al., 2022), prevents the adhesion and proliferation of microbial cells (Shafiei and Mostaghim, 2022). Despite of the advantages of the edible coating there are also some insufficiences of it. For example, the thickness of the coating can cause non-desired changes in appearance, flavor, color or texture of the coated fruit. Some compounds (lactose or gluten) in the coating composition could be allergenic (Priya et al., 2023; Lamani, 2023 – fig. 1). In addition, the barrier effect for gas exchange leads to anaerobic breathing and disturb the ripening (Momin et al., 2021). Nowadays, to enhance the advantages and eliminate the limitations of the edible coatings the composite, the emulsion and the herb coatings are in the center of the scientific research. These coatings contain polymers

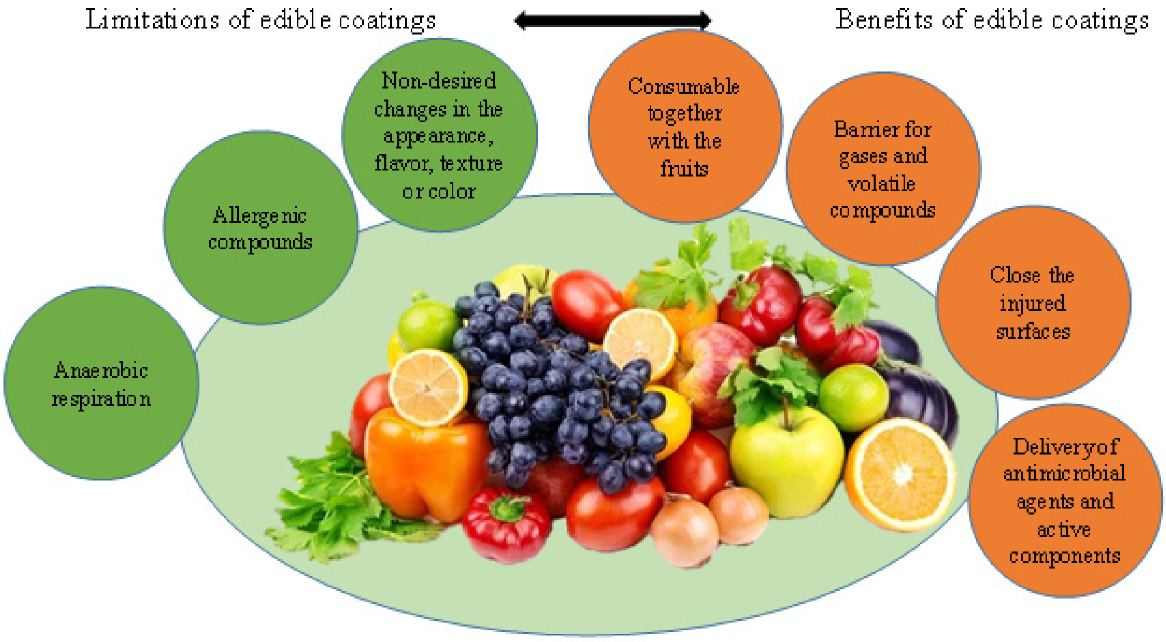

Fig. 1. Benefits and limitations of edible coatings

(polysaccharides, proteins and lipids), plaint oils or extracts in combination. The optimized edible coating recipes are capable to minimize the food waste in sustainable and economical way (Liyanapathiranage et al., 2023). These combined multicomponent coatings can be applies layer-by-layer or emulsion coating technique (Fu et al., 2022). The second technique is considered more effective because it is with less manipulation and without the possibility of delamination of the layers (Kumar et al., 2022).

Environmental friendly extraction methods of the chitosan

One of the most often used polysaccharide for edible coating is the chitosan, which is derived from the deacetylation of chitin under alkali conditions (Kumar and Shahid, 2020). The chitin can be extracted from the waste materials of the exoskeleton of crustaceans, cell walls of fungi, and other species (Mohan et al., 2022). The chitin extraction methods are influenced by cost effectiveness and environment friendliness.

► Chemical extraction: It is a harmful and expensive method with strong alkalis and acids, and with non-utilizable side-product and wastage. The strong chemicals disadvantageously affect the quality of extracted chitin. However, the extraction is relatively shorter than the green methods (Kaya et al., 2014; Younes et al., 2014).

► Green methods:

-Biological extraction (microbial fermentation): The proteolytic bacterial fermentation has higher chitin and chitosan yields than the chemical method and the received waste materials can be utilized as value-added by-products (Tan et al., 2020).

-Enzyme-assisted extraction: Fast and more specific action with reduced energy, chemicals and water consumption like the chemical extraction. It is characterized with the used specific enzymes: chitinases and chitozanases, nonspecific enzymes: carbohydrases and proteases. The efficiency of the mineralization is lower than that achieved with the chemical methods, but it can be increased by combination of the enzymes (Jegannathan and Nielsen, 2013).

-Microwave-assisted extraction: The demineralization is much-more effective than the regular heating and optimizable for quality and costs of the extraction (Nüchter et al., 2004).

-Subcritical water extraction: Subcritical water hydrolysis is usually carried out at temperatures between 100 to 374° C under enough high pressure (Pc of 22.1 MPa) to keep water in a liquid state. It is an environmental friendly method for the processing of the agricultural bio-waste (Yoshida et al., 2015).

-Extraction with ionic liquids with low melting point (under 100° C, e.g. 1-ethyl-3-methylimidazolium acetate). That method is capable to conduct the demineralization, deproteinization and chitin dissolution in a single step (Bradić et al., 2020).

-Ultrasonic-assisted extraction: The extraction time and temperature can be lowered by high intensity ultrasound signals (Suryawanshi et al., 2020). The quality of the resulted chitosan strongly depends on the intensity and the frequency (Mohan et al., 2022).

-Integrated electrochemical extraction: Electrochemical methods in combination with microwave irradiation can be used as an alternative of the chemical extraction, with better energy effectiveness and without hazardous residues in the wastewater (Kuprina et al., 2002).

Chitosan coatings in the circular economy

The main goals of the circular economy are reducing of the waste and developing the efficacy of the resources. The edible coating is a part of the circular economy, because it is able to mitigate the food waste, utilize the by-products of the local food production, and does not produce garbage (Chiralt et al., 2020). The chitosan, like an eco-friendly edible polymer is a base material or component of the edible coatings. It is extracted from the food waste and has antioxidant and antimicrobial effect (Abd El-Hack et al., 2020). The chitosan films have homogeny and stable structure, good barrier properties for water and good mechanical properties (Chaudhary et al., 2020). The functionality and other properties of chitosan depend on the molecular weight, deacetylation degree and other physicochemical properties (Weißpflog et al., 2021). In combination with plant extracts the functional and preservation properties of chitosan-based coatings can be improved (Popescu et al., 2022). Furthermore, the effect of chitosan-based coating can also be enhanced by the use of nanotechnology (Odetayo et al., 2022). Many literature sources deal with the study of the possibilities to replace the petroleum-based plastics in the food packaging industry, demonstrate the advantageous of the biodegradable, biocompatible biopolymers, like chitosan-based compositions (mixtures), and show new concepts for preparation and characterization of them (Priya et al., 2023). They speak about the evidence of the chitosan based films and coatings to meet with the requirements of alternative green bio packaging, but these materials are still not consolidated for commercial using (Pérez-Guzmán and Castro-Muñoz, 2020). May be the application of a new technique, "Deep eutectic solvents" opens a new way in preparing more stable and cost effective chitosan structures in the future (Khajavian et al. 2022; Wei et al. 2023).

The chitosan as a biodegradable packaging material

The biodegradation capability of the chitosan mainly depends on the degree of deacetylation, on the molecular weight and on the modifications. The solubility of chitosan restricts the application possibilities. The water-soluble chitosan derivatives have advantageous physicochemical and biophysical parameters and high application potential in the food industry (Faizuloev et al., 2012). The in vivo degradation path seems to be by unspecific enzymes but mainly lysozyme (Dash, et al., 2011; Kean and Thanou, 2011) with non-toxic oligosaccharides products. The degradation rate is inversely proportional with the crystallinity (Zhang and Neau, 2001) and the lower molecular weight increases it (Croisier and Jérôme, 2013; Rinaudo, 2006). Despite much research, the degradability of the chitosan is still not clear.

Conclusions

The chitosan based edible coating not just can improve the shelf life of the perishable fruit and vegetable production, but it is a cost effective packaging mode, which can reduce the food waste, utilize the by-products of the foodstuff and does not burden the environment with garbage. Due to the new green extraction methods and alternative sources, the chitosan is an economic alternative of the petroleum based packaging materials. Generally, still lots of research works are necessary to commercialize the edible coating as an industrial technology (Chavan et al., 2023).

Future work

In the future, the workgroup of the institute plan, will develop new layer-by-layer, multicomponent and herbs films or coatings based on chitosan with plant extract from different by-products of the food industry.

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