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Review

Chitosan films and coatings prevent losses of fresh fruit nutritional quality: A review

Garry Kerch

Department of Materials Science and Applied Chemistry, Riga Technical University, Riga, Latvia

A R T I C L E I N F O

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A B S T R A C T

Background: Consumption of fruits and vegetables, that are rich in antioxidant vitamins and polyphenols, can decrease the risk of the development of age-related chronic diseases. A gradual decline in moisture, sensory properties, vitamin C and polyphenols contents was observed during fruits and vegetables storage.

Scope and approach: The recent studies on the effect of chitosan-based coatings on the changes of nutritional quality of fruits and vegetables during postharvest storage have been summarized in this review. The latest data of the application of chitosan-based coatings for prevention of the decrease in contents of natural antioxidants ascorbic acid, anthocyanins, and total polyphenols in various fruits and vegetables during postharvest storage have been reviewed. The mechanisms of action and the role of polyphenols and vitamin C in prevention of age-related diseases has been also discussed.

Key findings and conclusions: Barrier and mechanical properties of chitosan-based films and coatings can be improved by the development of nanocomposite chitosan films and coatings incorporating also rosemary, sunflower, lavender, olive, and carp oils. Layer-by-layer self assembly can be used in the formation of multinanolayer edible coatings.

1. Introduction

Consumption of fruits and vegetables decreases the risk of the development of chronic diseases, such as hypertension, coronary heart disease, stroke (convincing evidence), cancer (probable evidence), rheumatoid arthritis, chronic obstructive pulmonary disease, asthma, osteoporosis, macular degeneration, cataract, dementia (possible evidence) (Boeing et al., 2012). Fruits and vegetables contain phytochemicals that have high antioxidant ability and free radical scavenging capacity (Li et al., 2014) and can prevent oxidative stress and oxidative stress-related diseases, such as cardiovascular diseases, cancer, aging, diabetes mellitus and neurodegenerative diseases. Oxidative stress can lead also to changes in protein conformation and to age-related protein conformational diseases such as Alzheimer's disease, cataract, diabetes mellitus and platelet aggregation and thrombus formation (Kerch, 2015).

Postharvest losses in nutritional quality of fruits and vegetables, particularly the reduction in vitamin C and polyphenols content due to physiological changes during storage, decrease health benefits from the consumption of fruits and vegetables (Lin & Zhao, 2007).

Antimicrobial and antioxidative activities of chitosans in food have been reported in a number of reviews (Friedman & Juneja, 2010; No, Meyers, Prinyawiwatkul, & Xu, 2007).

Edible coatings on fruits and vegetables during storage control moisture transfer, respiration rate, oxidation processes, and extend shelf life. Edible coatings can also give the same effect as modified atmosphere storage by modifying internal gas composition. Active ingredients can be incorporated into the edible coatings and consumed with the food, enhancing safety and nutritional quality (Dhall, 2013).

Chitosan based edible films and coatings have been recently reviewed (Dhall, 2013; Elsabee & Abdou, 2014; Shiekh, Malik, Al-Thabaiti, & Shiekh, 2013) and it has been concluded that chitosan has good antibacterial and antifungal properties for food protection, but it is necessary to improve mechanical properties, gas and water vapor permeability. This publication reviews the latest trends and research results concerning the positive effect of chitosan-based films and coatings on maintaining fruits nutritional quality during postharvest storage.

E-mail address: garrykerch@inbox.lv.

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2. Barrier and mechanical properties of chitosan-based films

Chitosan film prepared with acetic acid exhibited the highest tensile strength and the lowest percentage elongation (Adila, Suyatma, Firlieyanti, & Bujang, 2013; Kerch & Korkhov, 2011). Edible films prevent moisture losses during postharvest storage, so water vapor uptake and water vapor permeability are important parameters to characterize biopolymers that are used in design and fabrication of edible coatings. It has been shown that water vapor permeability rate increases with the increase of storage time, molecular weight of chitosan, drying temperature and with the decrease of storage temperature. Water vapor uptake of chitosan films decreases during storage at room temperature, but increases during storage at low temperatures in freezer and refrigerator. Thinner chitosan films have lower water vapor permeability (Kerch & Korkhov, 2011). Enhanced water vapor permeability has been observed also for composite gelatin/chitosan coatings as a result of the increase of coatings thickness (Poverenov et al., 2014). Chitosan-Na-montmorillonite nanocomposite films demonstrate increase in stiffness and strength (up to 100%) and a remarkable decrease in the elongation at break (up to 75%) and water vapor permeability (WVP) (up to 65%) (Giannakas, Grigoriadi, Leontiou, Barkoula, & Ladavos, 2014). The similar behavior was observed for chitosan/montmorillonite-K10 nanocomposite films (Kasirga, Oral, & Caner, 2012). Montmorillonite nanoclay and rosemary essential oil were incorporated into chitosan film to improve its physical and mechanical properties as well as antimicrobial and antioxidant behavior. The combined effect of clay and rosemary essential oil improves significantly the tensile strength and elongation of chitosan (Abdollahi, Rezaei, & Farzi, 2012). The antioxidant and antimicrobial edible zein/chitosan composite films fabricated by incorporation of phenolic compounds and dicarboxylic acids exerted better water vapor barrier and mechanical properties (Cheng, Wang, & Weng, 2015). The addition of sunflower oil to the quinoa protein/chitosan film improved the water vapor permeability as a result of hydrophobic interactions and the presence of clusters of hydrophobic masses on the surfaces of these films but reduced the film's tensile strength and oxygen permeability due to the formation of micropores and microfractures detected by SEM (Valenzuela, Abugoch, & Tapia, 2013). It was also found that tensile strength of chitosan film incorporated with 0.5 g/100 g gallic acid was significantly increased and water vapor permeability and oxygen permeability were significantly decreased (Sun, Wang, Kadouh, & Zhou, 2014b). Nanocrystalline cellulose reinforced chitosan-based biodegradable films demonstrate higher tensile strength and lower water vapor permeability (Khan et al., 2012). The tensile properties (Young modulus, strength and maximum elongation) of plasticized chitosan–olive oil emulsion films increased with olive oil concentration. Moisture sorption, water vapor permeation through the films and effective diffusion coefficients decreased as oil concentration increases, as a result of the non-polar nature of the lipid (Pereda, Amica, & Marcovich, 2012). Polyelectrolyte films based on chitosan/olive oil and reinforced with cellulose nanocrystals have been developed. The combined use of cellulose nanoparticles and olive oil proved to be an efficient method to reduce the inherently high water vapor permeability of plasticized chitosan films, improving at the same time their tensile behavior (Pereda, Dufresne, Aranguren, & Marcovich, 2014). Chitosan-based films containing lavender essential oil (0, 0.5%, 1.0%, 1.5% (v/v)) showed improved mechanical properties and decreased water vapor permeability (Zhang, Qin, Fan, Zhao, & Cheng, 2013). The addition of carp oil in the chitosan films showed an increase in the resistance to diffusion of water vapor compared with pure chitosan films. However, pure chitosan films showed better mechanical properties (Souza, Monte, & Pinto, 2013).

The efficiency of edible films and coatings is greatly affected by the water availability (Bonilla, Atarés, Vargas, & Chiralt, 2012). The correlation between moisture content in coated and non-coated strawberries and contents of vitamin C, anthocyanin and total phenols has been observed (Kerch, Sabovics, Kruma, Kampuse, & Straumite, 2011). A chitosan coating retarded water loss, increasing ascorbic acid content in sliced mango fruit (Chien, Sheu, & Yang, 2007). No correlation between moisture content and content of vitamin C, anthocyanins and total phenols has been found for cherries (Kerch et al., 2011).

It has been suggested that treatment with chitosan could induce a significant increase in the activities of superoxide dismutase (SOD), and catalase (CAT), and inhibited superoxide free radical production (Hong, Xie, Zhang, Sun, & Gong, 2012). Treatment with 2.0% chitosan delayed changes in chlorophyll and malondialdehyde (MDA) contents in guava fruit. The effects of chitosan on increase of antioxidant ability might be beneficial in delaying ripening process in guava fruit during cold storage (Hong et al., 2012). Chitosan-g-salicylic acid complex coating increased the endogenous salicylic acid concentrations and antioxidant enzyme activities including superoxide dismutase, catalase, ascorbate peroxidase and glutathione reductase in cucumber during storage (Zhang, Zhang, & Yang, 2015). It has been observed that production of superoxide free radicals and MDA was significantly decreased in the plums treated with combination of chitosan and ascorbic acid (Liu, Yuan, Chen, Li, & Liu, 2014).

3. Edible chitosan coatings in postharvest fruit and vegetables storage

Chitosan coatings delay the rate of respiration, decrease weight loss, and prolong the shelf life of fruits and vegetables during postharvest storage. The impact of chitosan-based edible coatings on shelf life, microbiological quality and biochemical processes during postharvest storage of fruits and vegetables has been described in a number of recent publications. The latest studies that have not been included in the recent reviews on edible coatings for fresh fruits (Dhall, 2013; Shiekh, R.A., Malik, Al-Thabaiti, & Shiekh, 2013) have been reported in this paper.

3.1. Vitamin C, or ascorbic acid

Age-related diseases such as atherosclerosis, hypercholesterolemia, and hypertension are related with endothelial dysfunction. This dysfunction is usually associated with decreased generation of nitric oxide (NO) by the endothelium. Vitamin C, or ascorbic acid, improves the defective endothelium-dependent vasodilation (Ashor, Lara, Mathers, & Siervo, 2014; Khan et al., 2014). The mechanism of the ascorbic acid effect can be attributed to an antioxidant function of the vitamin to enhance the synthesis or prevent the breakdown of NO. Multiple mechanisms that might account for the ability of ascorbate to preserve NO have been reviewed (May, 2000). These include ascorbate-induced decreases in low-density lipoprotein oxidation, scavenging of intracellular superoxide, direct reduction of nitrite to NO, and activation of either endothelial NO synthase or smooth muscle guanylate cyclase. On the other hand, it has been reported that chitosan oligosaccharides attenuate hydrogen peroxide-induced stress injury in human umbilical vein endothelial cells (Liu et al., 2009). Chitooligosaccharides also exerted preventive effects on suppressing the production of lipid peroxidation such as MDA, restoring activities of endogenous antioxidants including SOD, a key component of defense system, which protect cells and tissues from oxidative destruction, and glutathione peroxidase (GSH-Px), along with the

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