Innovative Food Science and Emerging Technologies 38 (2016) 231–237

Contents lists available at ScienceDirect

Innovative Food Science and Emerging Technologies

journal homepage: www.elsevier.com/locate/ifset

Chitosan-zinc oxide nanoparticle composite coating for active food packaging applications

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A R T I C L E I N F O

Article history:
Received 23 March 2016
Received in revised form 28 September 2016
Accepted 11 October 2016
Available online 12 October 2016

Keywords:
Polyethylene
Chitosan
ZnO nanoparticle
Nanocomposite
Active food packaging

A B S T R A C T

In this study antimicrobial properties of chitosan and chitosan-zinc oxide (ZnO) nanocomposite coatings on PE films were studied. Oxygen plasma pretreatment of PE films led to increased adhesion by 2% of chitosan and the nanocomposite coating solutions to the packaging films. Scanning Electron Microscopy (SEM) revealed uniform coatings on PE surfaces. Incorporation of ZnO nanoparticles into the chitosan matrix resulted in 42% increase in solubility; swelling decreased by 80% while the water contact angle (WCA) increased from 60° to 95° compared to chitosan coating. PE coated with chitosan-ZnO nanocomposite films completely inactivated and prevented the growth of food pathogens, while chitosan-coated films showed only 10-fold decline in the viable cell counts of *Salmonella enterica*, *Escherichia coli* and *Staphylococcus aureus* after 24-h incubation compared to the control.

Industrial relevance: One of the greatest challenges of food industry is microbial contamination. The present study suggests that PE coating with chitosan-ZnO nanocomposite is a promising technique to enhance antimicrobial properties of the films. Chitosan-ZnO nanocomposite coatings improved antibacterial properties of PE by inactivating about 99.9% of viable pathogenic bacteria. Hence, our results show the effectiveness of the nanocomposite coating in the development of active food packaging in order to prolong the shelf life of food products.

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Chemical compounds used in this article

Acetic acid (PubChem CID: 176); Chitosan (PubChem CID: 71853); Ethanol (PubChem CID: 702); ZnO (PubChem CID: 14806).

1. Introduction

Microbial contamination is one of the most common problems in food products which can lead to quality deterioration and reduce shelf life of products (Ding, Fu, & Smith, 2013). Packaging provides some level of protection to food products from external and internal unfavorable conditions (Mihindukulasuriya & Lim, 2014). Antimicrobial packaging offers enhanced protection to products by the incorporation of antimicrobial agents into the packaging film in order to inhibit microbial growth and extend the shelf-life of the product (Soares et al., 2009; Rocha, Ferreira, Souza, & Prentice, 2013). In this technology packaging materials are coated with antimicrobial agents leading to the death or inhibition of microbial growth on food surfaces. The incorporation of antimicrobial agents into the packaging material could enhance its functional properties by retarding microorganism growth and extending shelf life of food products (Rocha et al., 2013; Sirelkhatim et al., 2015).

Among the polymers used in food packaging, polyethylene (PE) is most popular due to its lower cost, high impact strength and reasonable chemical resistance (Franklin et al., 2007; Carrion, Sanes, & Bermudez, 2007). PE has relatively high gas permeability, lower sensitivity to oils but poor odour resistance and does not possess antimicrobial properties (Bag, Ghosh, & Maiti, 1998; Munteanu et al., 2014). Antimicrobial PE films can be prepared either by the incorporation and immobilization of antimicrobial agents to the polymer films or by the modification of film surface with coatings. Incorporation of antimicrobial agents into the PE matrix prior to film fabrication is limited due to the stability of the antimicrobial agents and their incompatibility with the PE polymer matrix (Theapsak, Watthanaphanit, & Rujiravanit, 2012). Therefore, PE surface modification and coating are normally used. Coating of plastic films with a polymer based solution is an inexpensive method often leading to a higher stability and adhesiveness of attached antimicrobial molecules (An, Kim, Lee, Paik, & Lee, 2000).

Chitosan (1–4 linked 2-amino-deoxy-β-D-glucan) is a well-known biopolymer that could inhibit the growth of wide varieties of fungi, pathogenic bacteria and spoilage microorganisms (Ravi Kumar, 2000; Dutta, Tripathi, Mehrotra, & Dutta, 2009). It has widespread application

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http://dx.doi.org/10.1016/j.ifset.2016.10.010
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in biomedical, chemical and food industries due to its antimicrobial activity, biocompatibility, biodegradability, high water permeability, low toxicity and susceptibility to chemical modifications (Kaushik et al., 2008; Munteanu et al., 2014). Chitosan is a partially deacetylated polymer of acetyl glucosamine that is a naturally occurring linear cationic polysaccharide. Chitosan is obtained through alkaline deacetylation of chitin, which can be extracted from a variety of crustacean shells, fungal cell walls and other biological materials (Coma et al., 2002, Kim et al., 2011). Antimicrobial activity of chitosan depends on the concentration, molecular weight and deacetylation degree (Shahidi, Arachchi, & Jeon, 1999; Chi, 2004). Chitosan solutions in various organic acids can be prepared which upon drying form flexible, clear and tough films that have been shown to be good oxygen barriers (Caner, Vergano, & Wiles, 1998; Bourtoom, 2008). In 2001, chitosan was classified as safe by the US FDA (Sagoo, Board, & Roller, 2002) and is thus considered safe to be used as a food preservative (Friedman & Juneja, 2010). In food industries, chitosan has been extensively used for direct surface coating of meat and fruit products to reduce food deterioration and water loss, as well as delay in the ripening of fruits (Hernández-Muñoz, Almenar, Ocio, & Gavara, 2006; Aranaz et al., 2009).

Antimicrobial activity and stability of chitosan can be enhanced by the incorporation of conducting polymers, metal nanoparticles and oxide agents (Dhillon, Kaur, & Kaur Bra, 2014). Though silver nanoparticles have proven antimicrobial effects, it is still not clear whether it is safe to use silver containing products in direct human exposure (Nowack, Krug, & Height, 2011; Echegoyen & Nerín, 2013; Cushen, Kerry, Morris, Cruz-Romero, & Cummins, 2014). Previous reports demonstrated that chitosan composite with inorganic metal oxides has increased stability and antibacterial activity (Applerot et al., 2009; Haldorai & Shim, 2013).

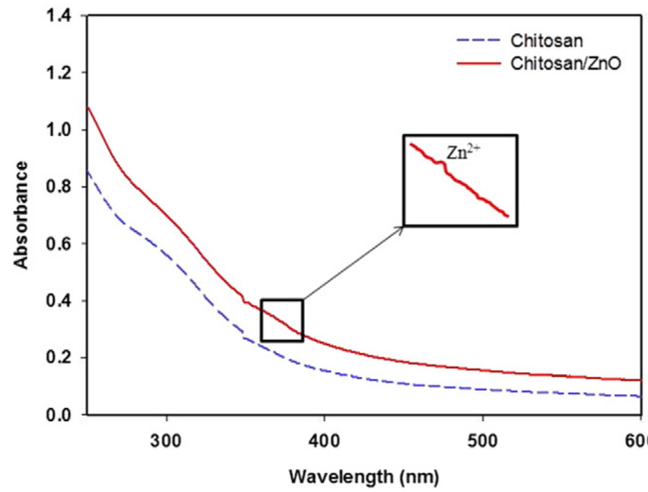

Fig. 2. UV/VIS spectra of chitosan and ZnO nanocomposite and chitosan (chitosan/ZnO) solutions. Inset — Zn^{2+} absorption peak.

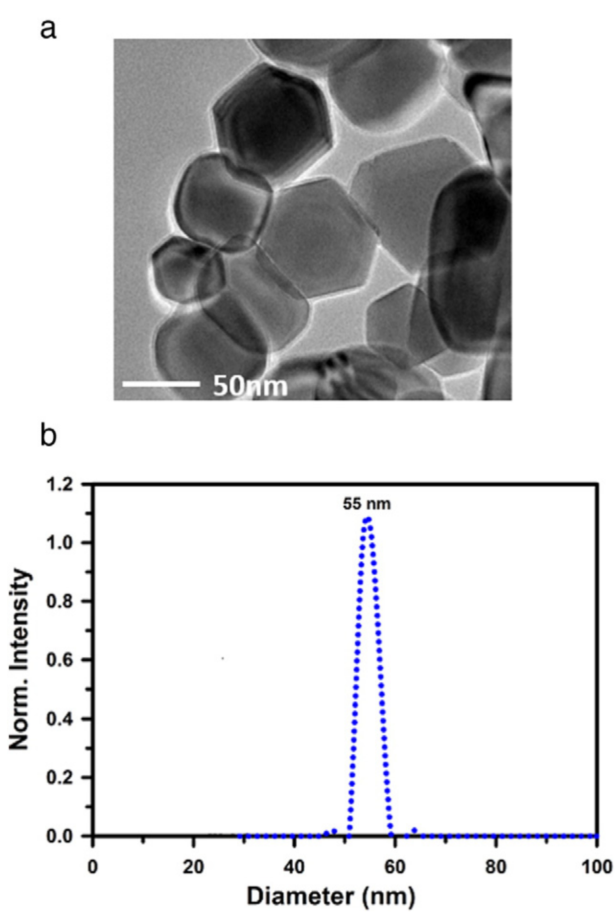

Fig. 1. (a) High resolution transmission electron micrograph of the commercial ZnO nanoparticles (35–45 nm) and (b) particle size analysis made from photocorrelation spectroscopy.

Among the metal oxides, zinc oxide (ZnO) is one of the most widely applied materials in various fields due to its remarkable antimicrobial and photocatalytic properties (Vasilache, Popa, Fiolte, Creto, & Benta, 2011). ZnO nanoparticles in comparison to other metal oxide nanoparticles are regarded as safe materials for human beings, and have been used as food additives, packaging materials and in water purification (Stoimenov, Klinger, Marchin, & Klabunde, 2002; Chaudhry et al., 2008; Bradley, Castle, & Chaudhry, 2011). ZnO has been introduced into a number of food packaging coatings to maintain food colors and avoid spoilage and improve packaging material properties, including mechanical strength, barrier properties and stability (Shi et al., 2014; Sirelkhatim et al., 2015). PE with chitosan-ZnO nanocomposite can enhance antimicrobial properties of active packaging but there are very few reports on the use of chitosan and ZnO nanocomposite for antimicrobial food packaging (de Azeredo, 2012; Sanuja, Agalya, & Umapathy, 2015).

In this study, antimicrobial activity of low density PE films coated with chitosan and ZnO-chitosan nanocomposite was investigated. The specific aims of this study were to: 1) coat PE with chitosan and ZnO-chitosan nanocomposite coatings; 2) characterize films using Fourier Transformation Infrared (FTIR) spectroscopy, water contact angle

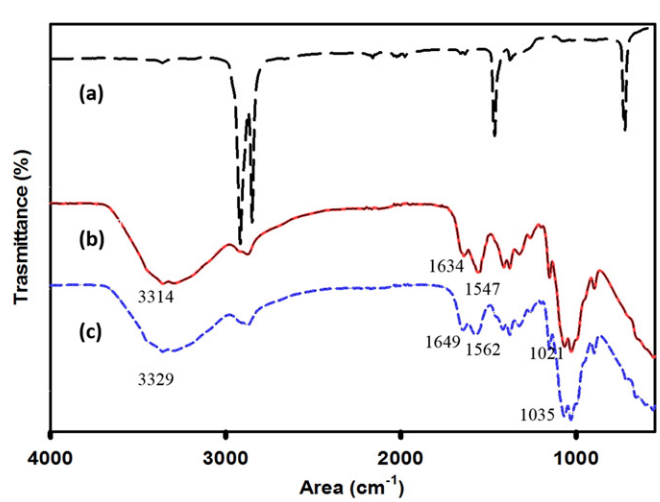

Fig. 3. FTIR spectra of polyethylene (PE) films coated with chitosan and chitosan-ZnO nanocomposite compared to uncoated PE: (a) uncoated PE, (b) PE coated with chitosan-ZnO nanocomposite, (c) PE coated with chitosan.

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