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Effect of ultraviolet radiation on morphological and physicochemical properties of sesame protein isolate based edible films

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ABSTRACT

The photo cross-linking effect of ultraviolet radiation on sesame protein isolate (SPI) based edible films was investigated. SPI films were produced by casting method and different UV light types (UV-A, UV-B and UV-C) were applied to film forming solution or to pre-formed films. The crystallinity index of films was increased according to XRD patterns. FE-SEM observation revealed that a more compact structure without pinholes and cracks was obtained by UV treatment. Moisture content, solubility and WVP were decreased and density and hydrophobicity of the films were increased after UV exposure. Mechanical properties were also improved and UV-C irradiated film forming solution exhibited the highest tensile strength (8.29 MPa) and Young's modulus (118.35 MPa). Generally, the UV radiation of films forming solution was more effective than pre-formed films and UV-C light had the highest potential in improving the properties of SPI films.

1. Introduction

With increasing awareness on environmental problems and decrease of petroleum resources, the production of environment-friendly biodegradable plastic materials derived from natural resources is of significant attention in both academic and industrial fields (Ghanbarzadeh & Almasi, 2013). Usually, the biodegradable film-forming substances are based on proteins, polysaccharides, lipids and resins or on a combination of these (Siracusa, Rocculi; Romani, & DallaRosa, 2008). Among bioresources, proteins have long been used as packaging materials. A variety of proteins from agricultural resources have received attention for the production of films.

Sesame (*Sesamum indicum* L.) is one of the important oilseeds cultivated in many tropical countries. Sesame seed has oil content between 45 and 55%. Sesame cake is a by-product of oil extraction process whose protein content can reach 50% depending on the variety and extraction method (Achouri, Nail, & Boye, 2012). The major parts of sesame protein include globulins (67.3%), albumins (8.6%), prolamines (1.4%), and glutelins (6.9%) (Nilo Rivas, Dench, & Caygill, 1981). Besides its high nutritional value, sesame protein can also be used as food additive. Foaming capacity, whippability, emulsifying activity and fat absorption capacity are some of the functional properties of sesame proteins (Cano-Medina et al., 2011). Sesame protein isolate (SPI) can be produced easily by isoelectric precipitation method. Because of inexpensive raw material (sesame oil extraction by-product), facile extraction process and interesting functional characteristics, sesame protein has become an attractive plant based protein with various applications. High molecular weight and good heat stability make SPI as a good candidate for film forming applications. Research on feasibility of edible films production from sesame proteins is rare. As the first report on sesame protein films, Lee, Song, Jo, and Song (2014) examined the effect of nanoclay type and content on the physical properties of these films. The second and last report on the sesame protein based edible films belongs to Sharma and Singh (2016), who optimized the protein concentration, pH, temperature and plasticizer content to achieve the films with the best mechanical, thermal and barrier properties.

Although protein films typically have excellent gas barrier

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properties, higher water vapor permeability and weaker mechanical characteristics are their shortcomings in comparison to most synthetic polymers. Various physical and chemical methods have been reported to enhance the mechanical and barrier properties of protein films. Cross-linking methods such as thermal, chemical or enzymatic cross-linking have been explored as a viable approach to improve the mechanical strength and barrier properties of protein films (Wihodo & Moraru, 2013). A new cross-linking method in protein films is cross-linking by radiation (Vachon et al., 2000). Several researches have been reported on the use of γ-irradiation as an ionizing radiation for treatment of protein films such as wheat gluten (Micard, Belamri, Morel, & Guilbert, 2000), sodium caseinates (Ressouany, Vachon, & Lacroix, 1998), calcium caseinates and whey protein concentrate (WPC) and isolate (WPI) films (Ciesäla, Salmieri, & Lacroix, 2006; Ouattara, Canh, Vachon, Mateescu, & Lacroix, 2002). The effect of γ-irradiation on sesame protein characteristics has also been studied (Afify, Rashed, Mahmoud, & El-Beltagi, 2011; Al-Bachir, 2016; Hassan, Mahmoud, Elmamoun, Adiamo, & Ahmed, 2018).

Non-ionizing radiation by ultraviolet (UV) light is another form of electromagnetic radiation used to enhance biopolymer film properties. Absorption of UV radiation by double bonds and aromatic rings causes free radical formation in amino acids (such as tyrosine and phenylalanine), which can then lead to the formation of intermolecular covalent bonds (Wihodo & Moraru, 2013). According to ISO classification solar irradiance standard, the UV radiation is divided into UV-A (315–400 nm), UV-B (280–315 nm) and UV-C (200–280 nm) by its wavelength region (Lee, Koo, & Kim, 2015). UV radiation as a physical, cheap, easy to operate and environmental-friendly (green) technology has received increasing attention during recent years (Shahabi-Ghahfarrokhi, Khodaiyan, Mousavi, & Yousefi, 2015a). UV radiation has been utilized to cross-link proteins in order to improve properties of various films such as wheat gluten, corn zein, and egg albumin films (Rhim, Gennadios, Fu, Weller, & Hanna, 1999), peanut protein (Liu, Tellez-Garay, & Castell-Perez, 2004), WPI (Kristo, Hazizaj, & Corredig, 2012) and WPC (Díaz, Candia, & Cobos, 2016), soy protein isolate (Rhim, Gennadios, Handa, Weller, & Hanna, 2000) and fish gelatin films (Otoni et al., 2012).

The effectiveness of the action of UV radiation on proteins depends on different variables. Physical state, thickness and composition of the material and also its turbidity and surface properties could affect the absorbed energy and transmittance of UV light. Therefore the changes could be different if the UV treatment is applied in the film forming solution or in the pre-formed film. There is very little information in this area. As the only research on this field, Díaz et al. (2016) applied UV treatment at different doses (0.12, 4.0 and 12.0 J cm^{-2}) to film forming solution or to pre-formed WPC films. According to their report, UV radiation affected mechanical and barrier properties of films only when applied to film forming solution and at the highest dose.

There are no reports on the effect of UV radiation applied to sesame proteins or SPI films. Moreover, to the best of our knowledge, there are no reports on the comparison of various UV light regions in the modification of protein films. The objective of this work, as the third research on SPI films, was to evaluate the effects of the UV radiation at different regions (UV-A, UV-B and UV-C) applied to film forming solutions or to pre-formed films on the mechanical, barrier, structural and morphological properties of SPI films.

2. Materials and methods

2.1. Materials

Glycerol, calcium sulphate, potassium sulphate, n-hexane, acids and bases and all other reagents (analytical grade) were purchased from Sigma Aldrich (Germany).

2.2. Extraction of sesame protein isolate (SPI)

Alkali method developed by Onsaard, Pomsamud, and Audtum (2010) with some modifications was used for SPI isolation. Defatted sesame cake was obtained from Dornika Co. (Piranshahr, Iran) and milled using a home grinder. Firstly, n-hexane was added at the ratio of 1:5 (w/v) with blending for 2 h and filtering to remove residual oil. After that, the sesame cake was mixed with water at a ratio of 1:6 (w/v). The pH of the suspension was adjusted to pH 7.5 using 1.0 M NaOH, continuously stirred with a magnetic stirrer for 2 h and centrifuged at 5000 rpm for 15 min for removing of solid residues. The supernatant containing soluble phases was collected and its pH was adjusted to pH 4.5 (pH isoelectric of SPI) using 0.1 M HCl due to which proteins precipitates. The suspensions were centrifuged at 5000 rpm for 15 min, after which the supernatant was poured away. The precipitate obtained was washed twice, and re-suspended in a minimum amount of water. After neutralization to pH 7.0 with NaOH, the SPI sample was then freeze-dried and stored at 4 °C until analyzed and used.

The chemical composition of SPI including moisture, protein, fat, fiber and ash contents was determined according to Association of Official Analytical Chemists AOAC (1994) standard methods. Elemental composition of SPI was studied by Energy Dispersive X-ray Spectroscopy (EDS) (EDAX Inc, Mahwah, NJ, USA) connected to a scanning electron microscope (SEM) (Hitachi 4300S, Japan) with an accelerating voltage of 18 kV. Before the analysis, samples were sputter-coated with a thin carbon layer to make them conductive.

2.3. SPI film preparation

SPI films were prepared by dissolving of 3 g SPI in 100 ml of distilled water. pH value of the solution was adjusted to 11 with 2 N NaOH. The solution was heated at 50 °C for 20 min and glycerol (40% w/w of SPI) was added as plasticizer. 35 ml of the solution was poured into Plexiglas Petri dishes of 9 cm diameter. For the preparation of UV untreated sample (Control), the Petri dishes were placed in an air forced oven and allowed to dry for 18 h at 50 °C. UV treatment in film forming solution and UV treatment in pre-formed film were used for preparation of UV treated films. For UV treatment in pre-formed films (UV-F), the untreated SPI solutions were dried in the same conditions that were described above. The dried films were peeled and subjected to UV radiation. For applying of UV treatment on film forming solutions (UV-S), the SPI solutions in Petri dishes were subjected to UV radiation before drying in the conditions mentioned above. UV treatments were applied to the dried films or the Petri dishes containing film forming solutions in a metal, light-tight cabinet equipped with UV lamps by placing of samples under UV lamps at a distance of 10 cm. Two 20-W UV lamps operating at different ultraviolet regions including UV-A, UV-B and UV-C were used for UV treatments. Film forming solutions and pre-formed films were irradiated for 6 h by these three types of UV lamps. The codes of UVA-S, UVB-S and UVC-S were used for irradiated film forming solutions and the UV treated pre-formed film samples were coded as UVA-F, UVB-F and UVC-F. The UV light intensity at the cabinet center was 0.8 mW m^{-2}, and the samples received a UV radiation dosage of 32.6 J m^{-2} over 6 h of exposure. The UV-S samples were dried after UV treatment and all films were conditioned at 25 °C and 50% relative humidity (RH) for 24 h before analysis.

2.4. Characterization of films

2.4.1. X-ray diffraction (XRD)

The XRD analysis was used to study structural properties of SPI films. X′ Pert Pro (PANalytical company, Netherlands) instrument operated at 40 kV and 40 mA was used. The machine was equipped with Cu Kα radiation at a wavelength of 0.1546 nm and a curved graphite crystal monochromator. Scanning range of diffraction angle and scanning rate were $2\theta = 5–40^{\circ}$ and 1°/min at room temperature,