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Experimental determination of penetration depths of various spice commodities (black pepper seeds, paprika powder and oregano leaves) under infrared radiation

S. Belgin Erdogdu [a], Lovisa Eliasson [b], Ferruh Erdogdu [c,*], Sven Isaksson [b], Lilia Ahrné [b]

[a] Department of Gastronomy and Culinary Arts, Faculty of Tourism, University of Mersin, Mersin, Turkey
[b] SIK, The Swedish Institute for Food and Biotechnology, Gothenburg, Sweden
[c] Department of Food Engineering, College of Engineering, Ankara University, Ankara, Turkey

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ABSTRACT

During infrared processing, transmitted energy is attenuated exponentially with penetration distance, and its intensity is gradually lost while passing through absorbing or scattering media. Penetration depth is a complex function of chemical composition of a food product, its physico-chemical state and physical properties and wavelength spectrum of energy source. Knowing penetration depth leads to better designing commercial sterilization processes for food products like spices. Therefore, the objective of this study was to determine penetration depth of various spices (paprika powder, black pepper and oregano) as a function of water activity under infrared processing conditions. For this purpose, spice samples were prepared at various water activity (a_w) levels, and heat flux measurements were carried out to determine the penetration depth. Penetration depth was determined to increase with increasing a_w for black pepper seeds and paprika powder while there was no significant change for oregano leaves as a function of a_w. Knowing penetration depth is important to design an effective infra-red processing system and an important issue for surface pasteurization processes since infrared radiation effects on microbial inactivation decrease with sample thickness.

1. Introduction

Infrared (IR) radiation, starting with exposing food products to intensive sunlight, is one of the oldest methods to process foods. Fundamental properties related to radiation involve absorption, reflection and transmission of the incident radiation with emitting. When electromagnetic energy (E) emitted by a source reaches to another body, a part might be reflected (R), a part might be transmitted (T) and a part might be absorbed (A) to lead for heating:

$$E = R + T + A \tag{1}$$

All these properties specifically depend upon the wavelength of the infrared source and physical properties of the food product, e.g. composition – moisture content, surface roughness – properties. Among these, absorptivity is a significant factor since IR absorption (fundamentally equal to emissivity when the material and IR source are at the same temperature) leads to heating due to increases in thermal molecular vibrational activity (Siegel and Howell, 2002). Transmitted energy is, however, attenuated exponentially with penetration, and attenuation factor determines energy absorption as a function of product depth (Sakai and Mao, 2006). The intensity is then gradually lost, and this loss is described by Beer–Lambert‘s law. The intensity of spectral radiation is attenuated exponentially as it passes through an absorbing or scattering medium (Howell et al., 2011):

$$I = I_0 \cdot \exp(-k \cdot x) \tag{2}$$

where I_0 is the incident energy flux ($\lim_{x\to 0} I = I_0$) along the surface (W/m^2), I is the energy flux at a distance x (W/m^2), and k is the spectral attenuation factor. ($\frac{1}{k} = \delta$) is then described as penetration depth (m) (Salagnac et al., 2004). As noted by Datta and Ni (2002), Ginzburg (1969) also assumed the IR power deposition as an exponential decay from surface to interior. In a computational modeling study, Allanic et al. (2007) used the Lambert–Beer law, as also suggested by Cairncross et al. (1995), to model IR radiation, transmitted through a polymer aqueous solution place in a petri-dish, with respect to the attenuation coefficient and the transmitted IR energy.

* Corresponding author. Tel.: +90 533 812 0686.
E-mail address: ferruherdogdu@yahoo.com (F. Erdogdu).

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Penetration depth is a complex function of chemical composition, physicochemical state (solid, liquid, powder, frozen or unfrozen, dispersion, emulsion, etc.) and physical properties (moisture content, density, porosity) (Sandu, 1986). Atungulu and Pan (2011) listed penetration depths for some food products as a function of IR source's wavelength. Penetration depth also depends upon wavelength spectrum of the energy source (Lloyd et al., 2003). Various studies focused on radiant emitters and stress the significance of their characterization for food processing applications. However, knowing eventual penetration of IR energy through surface is also significant to optimally design an infrared heating process. IR heating is successfully applied for heating product surfaces to a certain degree to achieve commercial sterilization while preventing quality degradations with overheating the whole product (Trivittayasil et al., 2011). In addition, for bulk production of particulate foods (e.g. spices), longer times are required since conduction from surface to interior is slower leading to quality degradations. This results in diminishing IR effect on microbial inactivation with increased sample thickness. Hence, for a proper design of an IR process, penetration depth is one key parameter while composition, especially water activity, has a certain effect. Since water might be regarded to be one of the main component of food products, variation in IR penetration can also be explained by water's strong absorption at wavelengths larger than 1. 4 μm (Dagerskog and Österström, 1979).

Spices are widely used ingredients. They are valuable commodities for their distinctive flavor–color–aroma and highly exposed to microbial contamination. Besides public health issues, heavy microbial contamination is a significant problem for export. Hence, developing a commercial sterilization system for spices is important. Erdogdu and Ekiz (2012, 2013) presented the potential of far-IR heating combined with ultraviolet radiation for surface pasteurization of black pepper and cumin seeds pointing out these issues for bulk production. Knowing penetration depth and thickness of the product going through an IR process lead to a better designing a commercial sterilization process for food products like spices. Therefore, the objective of this study was to determine the penetration depth of various spices (paprika powder, black pepper and oregano) as a function of water activity under IR heating conditions.

2. Materials and methods

2.1. Preparation of the spice samples

Black pepper seeds, paprika powder, and oregano leaves (Fig. 1) were chosen to experimentally determine penetration depth under near-IR heating conditions due to their commercial significance and various structural properties. Besides, use of IR for surface pasteurization of spices was already demonstrated in the literature, and knowledge of penetration depth under IR heating conditions would be valuable information for designing commercial sterilization processes. The given spice samples also demonstrate three various sample structural properties (particles – black pepper seeds, powder – paprika and leaves – oregano) to possibly affect IR penetration and possible moisture migration within the product during the IR heating process. To observe the moisture content effects, these spices were prepared at three water activity levels (a_w – 0.53–0.69–0.88 for black pepper seeds; 0.36–0.64–0.88 for paprika powder and 0.59–0.75–0.88 for oregano leaves) prior to IR heating experiments. For this purpose, spice samples were placed in a climate chamber and moisturized under various adjusted relative humidity values to reach to the given a_w values.

The climate chamber temperature was 25 °C, and the samples were left in the chamber and spreaded over the trays overnight (≈17–18 h). Following this, the spice samples were left again overnight in refrigerator for equilibration before conducting the experiments since there was a possibility of moisture difference among the layers of the spices spreaded over the trays. The a_w values of the spice samples were measured by using a water activity meter (AquaLab, Series 3, Pullman, WA), and three replicates were carried out. These a_w values corresponded to the moisture content values (obtained from the sorption isotherms) of 8%, 11%, 16% for black pepper seeds, 6%, 11% and 27% for paprika powder and 11%, 15% and 23% for oregano leaves, respectively.

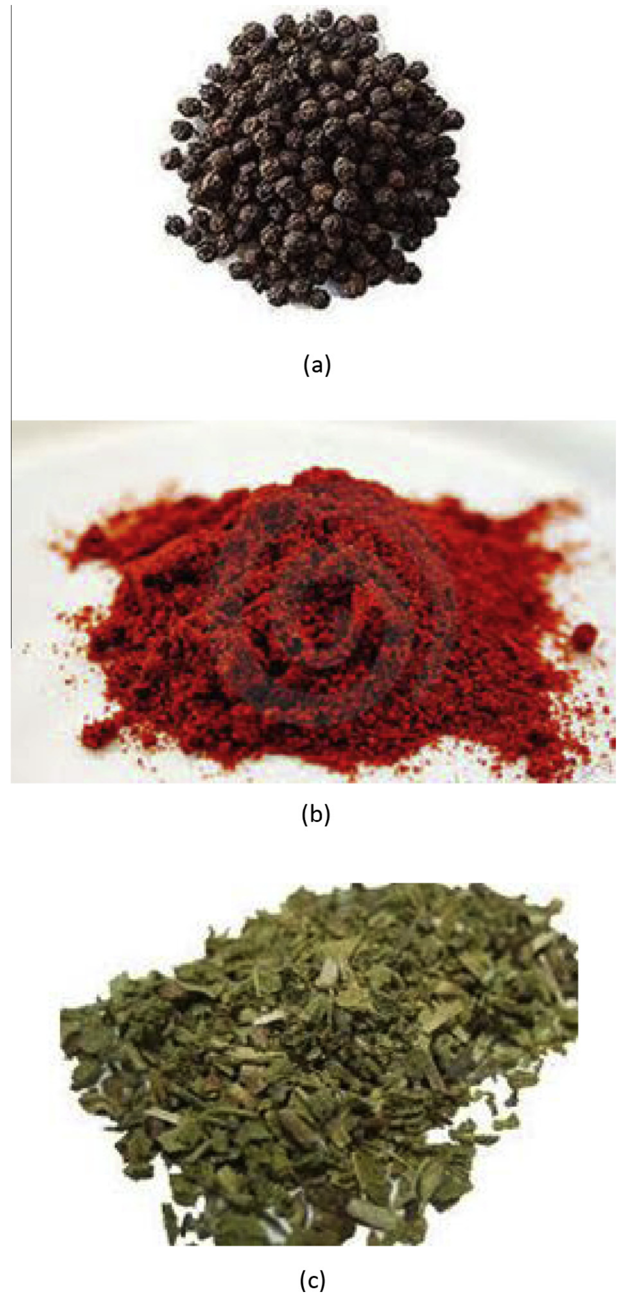

Fig. 1. Spices used in the experiments to determine the infrared penetration depth (a) black pepper seeds, (b) paprika powder and (c) oregano leaves.

To prepare the spice samples at various thicknesses (0.1–1.5 cm) for IR heating experiments and to determine the penetration depth, bulk density of each sample at the given a_w value was measured by using a densitometer (Jolting Volumeter STAV-II, Ludwigshafen, Germany), then a known mass amount of