LWT - Food Science and Technology 63 (2015) 846–851

Contents lists available at ScienceDirect

LWT - Food Science and Technology

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

Effect of X-ray, gamma ray, and electron beam irradiation on the hygienic and physicochemical qualities of red pepper powder

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A R T I C L E I N F O

Article history:
Received 5 February 2015
Received in revised form
7 April 2015
Accepted 9 April 2015
Available online 1 May 2015

Keywords:
Capsaicinoids
Capsanthin
Red pepper powder
Sensory evaluation
X-rays

A B S T R A C T

This study evaluated the total aerobic microbes (TAM), concentration of capsaicinoids and capsanthin, color, and sensory properties of red pepper powder (*Capsicum annum* L.) irradiated with gamma rays, electron beams, or X-rays using doses of up to 10 kGy. TAM decreased by irradiation in a dose-dependent manner. A dose of 6 kGy (for all radiation sources) reduced the TAM population effectively without affecting major quality indicators. The three radiation types did not change the pungency of red pepper powder based on the capsaicinoids content. The red color of the pepper powder was not significantly different for irradiated samples than that of the control, as determined from the capsanthin content and Hunter's values. Further, a sensory evaluation showed no significant difference in pungent odor or color between the non-irradiated control and irradiated red pepper powder. However, an off-flavor was detected by most panelists for the irradiated samples for all sources. In this study, X-ray, gamma ray, and electron beam irradiation were compared with respect to the sterilization of red pepper powder. The results indicate that X-rays can be used for the irradiation of dried condiments with the same effects as gamma rays and electron beams.

1. Introduction

Red pepper (*Capsicum annum* L.) powder is one of the most important spices, especially in Korea, and has been used worldwide as a natural flavoring and coloring agent owing to its unique spicy and pungent taste and color (Lee, Sung, Lee, & Kim, 2004). The pungency and natural red color are the main factors that determine the commercial quality of red pepper. The level of pungency of red pepper depends on the concentration of capsaicinoids, primarily capsaicin and dihydrocapsaicin. The red color is attributed to the presence of capsanthin, which is a major carotenoid pigment and exists only in the genus *Capsicum* (Minguez-Mosquera & Hornero-Mendez, 1994).

Red pepper powder is of agricultural origin and is therefore generally contaminated by microorganisms during the cultivation, drying, and grinding, and storage processes. Microorganisms may be potential contamination sources in foods even when added in small amounts. To sanitize red pepper powder, fumigation with ethylene oxide, steam heat sterilization, and irradiation are used to decontaminate undesirable microorganisms. The steam heat treatment is limited because it requires an additional decontamination step prior to packaging. Irradiation is more effective than ethylene oxide fumigation, which is restricted in many countries owing to possible toxic residues, in controlling microbial contamination without undesired effects (Diehl, 2002; Farkas, 2006; Farkas & Andrassy, 1988). The Joint FAO/IAEA/WHO Expert Committee confirmed that irradiation of up to 10 kGy does not produce toxicological hazards and nutritional or microbiological problems in foods (WHO, 1981). Dried foods, such as red pepper powder, are less sensitive to irradiation than hydrated foods, and their irradiation has been authorized at a maximum dose of 10 and 30 kGy in Korea and the United States, respectively (Olson, 1998).

Food irradiation can be performed using various radiation sources and energy levels: (i) gamma rays produced from radioisotopes cobalt-60 (1.17 and 1.33 MeV) or cesium-137 (0.662 MeV); (ii) electron beams (maximum energy 10 MeV) generated from machine sources; and (iii) X-rays (bremsstrahlung, maximum

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http://dx.doi.org/10.1016/j.lwt.2015.04.030
0023-6438/

energy 5 MeV) obtained by bombarding a high-density target with a high-power electron beam (Cember & Johnson, 2009). X-rays and gamma rays are composed of photons in the electromagnetic spectrum, while electron beams are a particulate radiation with a different energy level (Cleland & Stichelbaut, 2013; Gregoire et al., 2003). Therefore, the three types of radiation show differences in penetration activity and different effects on the microbiological and physicochemical qualities of food. Recently, the rising prices of cobalt-60 sources and increasing consumer concerns toward radioactive materials have created a favorable environment for the development of electron beam and X-ray machines. Efficient and powerful electron irradiators have entered the industrial market and have successfully been used for sterilization in other sectors such as medical supplies and cosmetics (Arvanitoyannis, 2010).

Previous studies that have compared the use of various radiation sources on foods have mostly involved gamma rays and electron beams. Unfortunately, comparative studies of all three radiation sources have rarely been reported. This study applied gamma rays, electron beams, and X-rays to red pepper powder to sterilize microorganisms, and the amount of capsaicinoids and capsanthin as well as the sensorial properties of each sample were investigated. Specifically, the aim of the study was to evaluate the effects of X-ray irradiation on the microbiological quality, color, pungency, and odor of Korean red pepper powder.

2. Materials and methods

2.1. Sample preparation and irradiation

Red pepper powder harvested from September to October of 2013 was purchased from a local market in Jeongeup, Korea. The average moisture content in red pepper powders was 7.8 ± 0.2%. The samples were immediately placed in sterilized oxygen-impermeable nylon polyethylene/polypropylene bags (20 × 30 cm, thickness: 0.07 mm; Sunkyung Co. Ltd., Seoul, Korea) and packaged to a thickness of 3.0 cm to minimize the variation in penetration depth among the radiation sources. National Institute of Standards and Technology reported that the thickness of polyethylene and polypropylene materials within 10 mm did not affect the penetration ability of gamma rays, electron beams, and X-rays in the stopping-power report for electrons and protons (NIST, 2005). The packaged samples were irradiated with a dose of 0 (control), 2, 4, 6, 8, or 10 kGy using one of the designated sources. Gamma irradiation was performed in a cobalt-60 gamma irradiator (AECL, IR-79, MDS Nordion Inc., Ottawa, Canada) at the Korea Atomic Energy Research Institute (Jeongeup, Korea) and its source strength was approximately 11.1 PBq. Electron beam irradiation and X-ray irradiation were performed with an ELV-4 electron beam accelerator (10 MeV) and an X-ray linear accelerator (7.5 MeV), respectively, at the EB-Tech Co. (Daejeon, Korea). Gamma, electron beam, and X-ray irradiation were conducted with a dose rate of 10 kGy/hr. The absorbed doses were measured using an alanine-EPR dosimetry system and the actual doses were within 5% of the target doses. After irradiation, the samples were used for subsequent experiments.

2.2. Microbial analysis

The non-irradiated and irradiated samples (10 g) with doses of 2, 4, 6, 8, and 10 kGy were homogenized for 2 min in a sterile Lab-blender 400 Stomacher Bag (Seward Medical, West Sussex, UK) containing 90 mL of 0.1% sterile peptone. To enumerate the total aerobic microbes (TAM), yeasts and molds, and coliforms, cultures were plated on Plate Count Agar, Potato Dextrose Agar, and Eosin Methylene Blue Agar (Difco Laboratories, USA), respectively. The plates were incubated at 35 °C for 48 h (TAM and coliforms) or 25 °C for 5 days (yeasts and molds). The number of colony forming units (log CFU) per gram was counted after the culture was diluted such that the cell concentration was in the range of 30–300 CFU per plate. Experiments for each group of microbes were independently conducted in triplicate. D_{10} values for TAM were determined to compare the inactivation effects of the different radiation treatments, by calculating the reciprocal of the slope.

2.3. Sensory evaluation

A sensory evaluation was carried out for each sample immediately after irradiation (with gamma rays, electron beams, or X-rays) by ten trained panelists consisting of members of the Team for Radiation Food Science and Biotechnology of the Atomic Energy Research Institute. Both irradiated (2, 4, 6, 8, and 10 kGy) and non-irradiated samples were provided to panelists along with an explanation of the purpose of irradiation, and evaluated in terms of the pungent odor, color, and off-flavor. According to the method described by Civille and Szczesniak (1973), a sensory test was administered to panelists using a 7-point scale, where "7" means the panelist liked the sample extremely and "1" means the panelist disliked the sample extremely. The off-flavor was evaluated on a scale from 1 to 7, where 7 indicates very strong and 1 indicates no off-flavor. The samples were placed on a white plastic dish and labeled randomly with three-digit numerical codes.

2.4. Determination of Hunter's color values

To quantify the color of samples in terms of Hunter's L^* (lightness), a^* (redness), and b^* (yellowness), each sample was put in a petri dish (⌀ = 5 cm) and measured using a spectrophotometer (Konica Minolta CM-5, Tokyo, Japan). For each treatment, five measurements along the equatorial area of ten samples were obtained. The color difference (ΔE^*_{ab}) was calculated from the following equation:

$$\Delta E^*_{ab} = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2}.$$

2.5. Analysis of capsaicinoids

Irradiated red pepper powder (1 g) was mixed with 10 mL of methanol in a vial with a screw-cap and extracted in a shaking incubator (180 rpm) at 30 °C for 4 h. After centrifugation (1500 rpm, 10 min, 4 °C), the extracts were filtered through a 0.45-μm syringe filter, and an aliquot (10 μL) of the filtrate was injected directly into the high-performance liquid chromatography system (HPLC). The HPLC system consisted of a dual pump and a UV detector set at 280 nm (Agilent Technologies 1200 series, Santa, Clara, CA, USA). The column was Nova-Pak C18 (4 μm, 150 × 3.9 mm inner diameter; Waters, Milford, MA, USA). The isocratic mobile phase was a mixture of methanol/water (60:40 v/v) with a flow rate of 0.8 mL/min. As a standard compound, a synthetic chemical of capsaicin and dihydrocapsaicin was purchased from Sigma–Aldrich (St. Louis, MO, USA).

2.6. Analysis of capsanthin

Irradiated red pepper powder (0.03 g) was extracted with 4 mL of diethyl ether/methanol (50:50, v/v) in a shaking incubator (180 rpm) at 30 °C for 4 h until colorless extracts were obtained. After centrifugation (1500 rpm, 4 °C) for 10 min, the supernatants were treated with 20% KOH in methanol for 1 h at room