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The comparative effect of steaming and irradiation on the physicochemical and microbiological properties of dried red pepper (*Capsicum annum* L.)

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ABSTRACT

The comparative effects of steaming and gamma irradiation on the physicochemical and microbiological properties of dried red pepper (*Capsicum annum* L.) were investigated during post-treatment storage at refrigerated (4 ± 2 °C) and room (20 ± 2 °C) (RT) temperatures for 6 months. Whole dried peppers were either steamed, hot air-dried and processed into powder form or powderised, packed in PE bags and gamma-irradiated at 10 kGy. The commercial steam treatment led to a 1- to 2-log reduction in the initial microbial load (10^6 CFU/g) accompanied with changes in spice as indicated by low Hunter's colour values and reduced sensory scores in RT-stored samples. However, irradiation resulted in a 5-log reduction with minimal effects on the physicochemical properties, except for the decreased content of capsanthin in the irradiated samples. The functional components of spices were not apparently affected by both treatments. The refrigerated storage following irradiation is recommendable for powdered red pepper to minimise physicochemical changes.

1. Introduction

Known for its characteristic flavour and pungency, red pepper is cultivated worldwide and consumed fresh or in dried powdered form as a food ingredient. This pungent spice is primarily used to impart a bright red colour and enhance the flavour of many processed foods. Since red pepper powders are of agricultural origin, they are often contaminated with high levels of moulds, yeasts and bacteria (Banerjee & Sarkar, 2003; Buckenhuskes & Rendlen, 2004; Oularbi & Mansouri, 1996), which then results in a rapid spoilage of the foods they are supposed to enhance. Furthermore, the presence of pathogenic bacteria like *Clostridium perfringens*, *Staphylococcus aureus*, and *Bacillus cereus*, and high levels of aflatoxin B_1 were found in powdered red pepper (Aydin, Erkan, Baskaya, & Ciftcioglu, 2007; Banerjee & Sarkar, 2003; Buckenhuskes & Rendlen, 2004). Contaminated spices can result in a serious foodborne illness when they are added to foods that do not undergo further cooking such as processed meat. Recently, a multi-state outbreak of *Salmonella* in USA has been traced to ground pepper products (KPIC, 2009).

Superheated steam treatment was reported to reduce the number of microorganisms in paprika (Almela, Nieto-Sandoval, & Fernandez-Lopez, 2002). While steam-treated pepper is readily accepted by consumers as it does not involve the use of chemicals, the application of high-temperature steam is associated with colour degradation, a decrease in volatile oil content, and an increase in moisture content of the spices which leads to a decreased shelf-life (Almela et al., 2002; Lilie, Hein, Wilhelm, & Mueller, 2007). Irradiation of dried spices is also widely recognised and is now legally accepted in at least 51 countries with a maximum overall average of 10 kGy (IAEA, 2008). In some countries, such as Australia and USA, up to 30-kGy dose is permitted. Irradiation at 10 kGy was found to be effective in destroying bacteria and moulds without affecting the quality attributes of different spices (Farag, Aziz, & Attia, 1995; Munasiri et al., 1987; Onyenekwe & Ogbadu, 1995; Sharma, Padwal-Desai, & Nair, 1989).

At present, there are limited studies on the comparative effects of steaming and irradiation on the chemical properties of commercial spices, except for a study on ground black pepper, which revealed that irradiation was superior to high-temperature steaming in terms of microbial decontamination (Waje, Kim, Kim, Todoriki, & Kwon, 2008). Thus, this study was intended to compare and evaluate the effects of steaming and irradiation treatments on the physicochemical and microbiological properties of red pepper powder during the post-treatment storage.

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2. Experimental

2.1. Sample preparation, treatment and storage

Whole dried red peppers were divided into three lots (~1 kg each). One lot was steamed under the commercial conditions of a batch type at 1020 mbar and about 100 °C for 16 min using a steam steriliser (DEBAC, Bucher, France). The steamed peppers were processed into powder form using a sterile Waring blender (Dynamic Corp. of America, New Hartford, CT). The second lot was also powderised, packed in polyethylene bags and irradiated at 10 kGy using a Co-60 gamma irradiator (100 kCi point source AECL, IR-79, MDS Nordion International Co. Ltd., Ottawa, ON, Canada) with a dose rate of 2.5 kGy/h at room temperature. The absorbed dose was verified with a ceric/cerous dosimeter (Bruker Instruments, Rheinstetten, Germany) with a dose uniformity of 1.05 (Dmax/Dmin) (ASTM, 1995). The third lot, which served as control, was powderised and packed in polyethylene bottles. All samples were stored at 4 ± 2 °C and analysed for physicochemical and microbiological qualities. Samples from each lot were subdivided into two. The first half was kept refrigerated at 4 ± 2 °C and the other half was kept at 20 ± 2 °C. All analyses were repeated after 6 months of storage.

2.2. Microbiological analysis

All samples were analysed for the total aerobic bacteria, yeasts and moulds, and coliforms. Five grams of the pepper powder were mixed with 45 ml sterile peptone water. Subsequent dilutions were prepared and plated on Plate Count Agar for the total aerobic bacteria, Potato Dextrose Agar (acidified with 10% tartaric acid) for yeasts and moulds, and Desoxycholate Agar for coliforms. Microbial counting was performed 24–48 h after incubation at 30 °C and 37 °C for total aerobic bacteria and coliforms, respectively. Yeast and mould colonies were counted 3 days after incubation at 30 °C.

2.3. Analysis of chemical properties

The moisture content of steamed or irradiated red pepper powder (1 g each) was determined using an Infrared Moisture Determination Balance (FD-240, Japan) (Bradley, 2003). Pepper extracts were prepared by mixing 2 g powder sample with 80 ml distilled water in a shaker-incubator for 3 h at 200 rpm. The mixture was centrifuged and the supernatant was filtered (Whatman No. 41). The pH of the extract was obtained using a pH metre (Thermo Scientific Orion Star Series, USA) based from the method of Friedrich (2000). The extractable yield content was determined by placing a 2 ml sample extract in an aluminium disk having a pre-determined constant weight and dried in an oven at 105 °C until a constant weight was obtained (Waje et al., 2008). The total reducing sugar contents of the powder samples were determined using the modified Somogyi method (Kobayashi & Tabuchi, 1954). Analysis of the total soluble pigment was done by measuring the absorbance of the pepper extract at 420 nm using a UV–vis spectrophotometer (Optizen 2120UV, Korea) following the method described by Waje et al. (2008).

2.4. Analysis of functional components

The 1,1-diphenyl-2-picrylhydrazyl (DPPH) scavenging activity of pepper was determined according to the method of Blois (1958). The capsanthin content was analysed by measuring the absorbance of the acetone extract of the sample at 460 nm based from the AOAC method (2000) on extractable colour in spices. The capsaicin content of red pepper powder was also determined according to the AOAC method (2000).

2.5. Determination of Hunter's colour values

The Hunter's colour *L*- (lightness), *a*- (redness), and *b*- (yellowness) values were determined using a Colorimeter (Minolta CR-200, Japan). Powdered samples were spread onto a piece of paper and measurements were taken at three random locations. A numerical total colour difference (ΔE) was calculated from the Hunter values obtained (Horvath & Hodur, 2007).

2.6. Sensory evaluation

The peppers were evaluated for colour, odour, pungent taste, and overall acceptability by 15 judges. The panellists, who consisted of graduate students from the Department of Food Science and Technology, Kyungpook National University, Korea, were instructed to record their ratings using a 5-point hedonic scale (5 = like very much; 1 = dislike very much for colour, odour, and overall acceptability, and 5 = very strong; 1 = very weak for pungent taste) (Moskowitz, Muñoz, & Gacula, 2003).

2.7. Statistical analysis

Results from the measurements ($n = 3$) were analysed statistically using the Statistical Analysis System for Windows V8. Analysis of Variance and Duncan's Multiple Range Test were employed.

3. Results and discussion

3.1. Microbiological quality

The untreated red pepper contained a relatively high population of aerobic bacteria (10^6 CFU/g) (Table 1), but treatment with irradiation reduced the population by five logs. Similarly, a dose of 10 kGy reduced the total aerobic bacteria by 4–5 logs in powdered hot pepper (Farag et al., 1995), red chili pepper (Munasiri et al., 1987), and ground black pepper (Waje et al., 2008). Steaming treatment slightly decreased (1 log) the total plate count in peppers. These results illustrate that irradiation is a better decontamination method than steaming treatment in disinfecting spice powders. A 2-log reduction in the yeasts and moulds was observed in steamed and irradiated peppers while coliforms were not detected in both samples. No considerable changes in the population of aerobic bacteria were observed after storage at refrigerated temperature but the count slightly increased (1 log) in irradiated samples stored at room temperature. On the other hand, the yeast and mould counts decreased to non-detectable level in both treated peppers after storage. The coliform count slightly increased in the steamed red pepper stored at room temperature.

3.2. Chemical properties

Steam-treated pepper exhibited slightly higher moisture content than that of the control and irradiated ones (Table 2). The application of high-temperature steam to whole spices results in a condensation of moisture on the surface of the particles which if not properly air-dried and rapidly cooled could lead in an increased moisture content of the spice powder (Schweiggert, Carle, & Schieber, 2007). On the other hand, the irradiated pepper showed lower moisture content compared with that of the control. Radiation is known to induce depolymerisation of polysaccharides (Wilkinson & Gould, 1996) and this radiation-induced damage causes considerable changes in the cell membranes and connective

Table 1
Microbial count (CFU/g)[a] of control, steamed, and irradiated (10 kGy) red pepper powder stored at 4 ± 2 °C and 20 ± 2 °C during 6 months.

Microorganism	Month	Refrigerated temperature (4 ± 2 °C)			Room temperature (20 ± 2 °C)		
		Control	Steamed	Irradiated	Control	Steamed	Irradiated
Total plate count	0	2.1×10^6	1.1×10^5	1.8×10^1	–	–	–
	6	1.5×10^6	1.4×10^5	9.2×10^1	1.1×10^6	6.5×10^4	1.0×10^2
Yeasts and moulds	0	4.6×10^3	1.0×10^1	2.5×10^1	–	–	–
	6	1.2×10^1	<10	<10	<10	<10	<10
Coliforms	0	6.1×10^1	<10	<10	–	–	–
	6	<10	<10	<10	2.2×10^1	1.2×10^1	<10

[a] Mean of three replications.

Table 2
Chemical properties[a] of control, steamed, and irradiated (10 kGy) red pepper powder stored at 4 ± 2 °C and 20 ± 2 °C for 6 months.

Parameter	Month	Refrigerated temperature (4 ± 2 °C)			Room temperature (20 ± 2 °C)		
		Control	Steamed	Irradiated	Control	Steamed	Irradiated
Moisture content (%)	0	10.00 ± 0.13 bx	10.56 ± 0.05 ax	9.04 ± 0.11 cx	–	–	–
	6	9.88 ± 0.34 ax	9.56 ± 0.24 ay	9.39 ± 0.29 abx	7.75 ± 0.39 d	8.47 ± 0.60 c	8.74 ± 0.32 bc
pH	0	5.22 ± 0.06 ax	5.18 ± 0.02 ax	5.13 ± 0.03 ax	–	–	–
	6	5.05 ± 0.02 ay	4.98 ± 0.01 bcy	5.00 ± 0.02 by	4.96 ± 0.03 cd	4.86 ± 0.01 e	4.94 ± 0.02 d
Yield (%)	0	0.62 ± 0.01 by	0.66 ± 0.01 ay	0.60 ± 0.01 cy	–	–	–
	6	0.92 ± 0.09 bx	0.97 ± 0.01 abx	0.99 ± 0.02 abx	0.95 ± 0.02 ab	0.93 ± 0.03 b	1.05 ± 0.09 a
Total reducing sugar (% d.b.)	0	13.76 ± 0.18 ax	13.17 ± 0.06 bx	13.29 ± 0.10 bx	–	–	–
	6	11.69 ± 0.37 ay	11.29 ± 0.12 by	11.70 ± 0.31 ay	11.87 ± 0.01 a	9.95 ± 0.14 c	12.02 ± 0.04 a
Total soluble pigment (O.D. 420 nm)	0	0.23 ± 0.00 by	0.32 ± 0.00 ay	0.23 ± 0.00 by	–	–	–
	6	0.56 ± 0.05 dx	0.80 ± 0.02 bx	0.60 ± 0.06 dx	0.73 ± 0.01 bc	0.90 ± 0.00 a	0.70 ± 0.05 c

[a] Mean of three replications ± standard deviation. Values followed by the same letters within the row (a–e) and within the column per parameter (x–y) are not significantly different ($p < 0.05$).

tissues (Josephson & Peterson, 1982) leading to softening and easier water release in foods. After 6 months of storage, the moisture contents decreased in both control and treated peppers and the decrease was greater in samples stored at room temperature. Steaming and irradiation treatments did not significantly affect the pH of the samples but the values slightly decreased after storage. It was also noted that the pH was relatively lower in samples stored at room temperature than that of the refrigerated ones. The decrease in pH during storage was probably due to an increased amount of organic acids released during irradiation and steam treatments. The extractable yield, on the other hand, increased considerably in all the samples after storage. This could be attributed to the increase of dry matter content during storage and polysaccharide depolymerisation of the spice. Storage temperatures did not considerably affect the extractable yields of the samples. A slight, but significant decrease in the reducing sugar was observed in both steamed and irradiated pepper. After storage, the reducing sugar contents decreased in all the samples regardless of the storage temperature. This could be due to non-enzymatic browning reactions, involving reducing sugars and amino acids, that occurred as a result of steam treatment, radiation processing, and storage of red peppers. Previous researches have shown that thermal or irradiation treatment and prolonged storage of food containing substantial amount of reducing sugars and amino acids could cause non-enzymatic browning reactions (Chawla, Chander, & Sharma, 2009; Gogus & Eren, 1998), resulting in the darkening of the food and decreased amount of reducing sugars. Earlier studies conducted by Kwon, Byun, and Cho (1984) also revealed a decrease in the reducing sugar content of irradiated and non-irradiated red pepper during storage. Steaming treatment resulted in an increased total soluble pigment content in the pepper and the values further increased after storage in both room and refrigerated conditions. This increase in the absorbance of the pepper extract may be due to thermal depolymerisation as a consequence of steaming process resulting in improved extractability of the pigment.

3.3. Functional components

Steamed red pepper exhibited high DPPH radical-scavenging activity even after 6 months of storage (Table 3). According to Suresh, Manjunatha, and Srinivasan (2007), chemical alteration could occur to the components in pepper during heat treatment which then results in an increased extractability of some compounds in the spice. The antioxidant activity increased in all samples after storage regardless of the storage temperature. Similarly, Suhaj, Racova, Polovka, and Brezova (2006) and Waje et al. (2008) observed an increase in the DPPH radical-scavenging activity of irradiated and non-irradiated black pepper after 5 and 6 months of storage which was attributed to the increased dry matter content of the spice. The capsanthin content was lowest in irradiated red pepper even after storage at refrigerated or room temperature. Kwon et al. (1984) also found that capsanthin content of red pepper powder decreased with irradiation treatment. The capsaicin content, on the other hand, was not affected by both steaming and irradiation treatments but slightly decreased after storage. The functional components analysed in this study exhibited lower contents in samples stored at room temperature than those stored at refrigerated conditions, indicating the importance of keeping red pepper powder at low temperature.

3.4. Hunter's colour values

Colour degradation was greater in steamed red pepper than in irradiated samples as indicated by lower *L*-, *a*- and *b*-values of steam-treated samples (Table 4). The steamed pepper became darker and its degree of redness (*a*-value) and yellowness (*b*-value) was less intense. After storage, the colour values of steamed samples increased slightly under refrigerated conditions, and the *L*- and *a*-values were significantly lower in samples stored at room temperature. The *L*- and *b*-values of irradiated pepper slightly increased after storage but the *a*- and *b*-values were lower in the samples stored at room temperature compared to those at refrigerated conditions. Moreover, the irradiated samples constantly showed significantly lower *a*-values than that of the control. Colour of the untreated samples did not significantly change during storage but the *b*-value was relatively lower in the samples under room temperature. These findings demonstrated that red pepper powders should be stored under refrigerated conditions to minimise the colour degradation as a result of thermal and irradiation treatments. In studying the effect of thermal treatment on the colour properties of paprika, Almela et al. (2002) noted that high-temperature promotes colour degradation as the paprika became darker and the intensities of reddish and yellowish hues became lesser. However, the degradation was less pronounced in paprika stored under refrigerated conditions. Waje et al. (2008) also reported that steaming treatment of black pepper resulted in the darkening of the spice. With regards to irradiated pepper, Kim, Kausar, Kim, and Kwon (2005) found that the Hunter's lightness (*L*-value), redness and yellowness of dried pepper decreased after irradiation. They also observed that the storage period was more influential than irradiation treatment in the colour changes of red pepper powder. In this study, the overall changes in colour (ΔE, NBS) of red pepper revealed that storage at room temperature had a greater effect than steaming or irradiation treatment on the colour changes of the spice. Nevertheless, all samples exhibited trace (0.03–0.33) to slight (0.84–1.05) colour difference only.

Table 3
Functional components[a] of control, steamed, and irradiated (10 kGy) red pepper powder stored at 4 ± 2 °C and 20 ± 2 °C for 6 months.

Parameter	Month	Refrigerated temperature (4 ± 2 °C)			Room temperature (20 ± 2 °C)		
		Control	Steamed	Irradiated	Control	Steamed	Irradiated
Electron-donating ability (% d.b.)	0	57.72 ± 0.83 by	73.63 ± 1.01 ay	57.46 ± 1.86 by	–	–	–
	6	76.92 ± 0.47 dx	90.42 ± 0.67 ax	82.17 ± 0.57 bx	71.65 ± 1.20 e	77.35 ± 0.29 d	80.70 ± 1.15 c
Capsanthin (O.D. 460 nm)	0	0.47 ± 0.00 ax	0.46 ± 0.00 bx	0.43 ± 0.00 cx	–	–	–
	6	0.41 ± 0.01 ay	0.38 ± 0.02 by	0.36 ± 0.00 cy	0.29 ± 0.01 d	0.29 ± 0.02 d	0.23 ± 0.00 e
Capsaicin (mg/g d.b.)	0	0.56 ± 0.00 ax	0.56 ± 0.01 ax	0.55 ± 0.02 ax	–	–	–
	6	0.52 ± 0.00 ay	0.52 ± 0.01 ay	0.52 ± 0.02 ax	0.48 ± 0.01 bc	0.47 ± 0.01 c	0.49 ± 0.01 b

[a] Mean of three replications ± standard deviation. Values followed by the same letters within the row (a–e) and within the column per parameter (x–y) are not significantly different ($p < 0.05$).

Table 4
Hunter's colour values[a] of control, steamed, and irradiated (10 kGy) red pepper powder stored at 4 ± 2 ° and 20 ± 2 °C for 6 months.

Hunter's parameter[b]	Month	Refrigerated temperature (4 ± 2 °C)			Room temperature (20 ± 2 °C)		
		Control	Steamed	Irradiated	Control	Steamed	Irradiated
L	0	50.85 ± 0.32 ax	48.17 ± 0.13 cy	50.10 ± 0.17 by	–	–	–
	6	50.91 ± 0.19 ax	49.25 ± 0.15 bx	51.15 ± 0.56 ax	51.41 ± 0.12 a	48.27 ± 0.14 c	51.21 ± 0.25 a
a	0	21.53 ± 0.29 ax	19.54 ± 0.09 cy	20.78 ± 0.24 bx	–	–	–
	6	21.88 ± 0.30 ax	19.93 ± 0.11 cx	21.13 ± 0.44 bx	20.21 ± 0.19 c	17.68 ± 0.08 e	18.75 ± 0.41 d
b	0	25.03 ± 0.54 ax	21.50 ± 0.23 by	25.00 ± 0.07 ay	–	–	–
	6	25.27 ± 0.39 bx	22.99 ± 0.40 cx	26.39 ± 0.81 ax	24.80 ± 0.19 b	20.44 ± 0.33 c	24.89 ± 0.35 b
ΔE	0	0.00	0.23	0.33	–	–	–
	6	0.19	0.03	0.17	1.05	0.84	1.37

[a] Mean of three replications ± standard deviation. Values followed by the same letters within the row (a–e) and within the column per parameter (x–y) are not significantly different ($p < 0.05$).
[b] Hunter's parameters: *L*, degree of whiteness (white +100 → 0 black); *a*, degree of redness (red +100 → −80 green); *b*, degree of yellowness (yellow +70 → −80 blue); and ΔE: overall colour difference ($\sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$).

Table 5
Sensory properties[a] of control, steamed, and irradiated (10 kGy) red pepper powder stored at 4 ± 2 °C and 20 ± 2 °C for 6 months.

Sensory parameter	Month	Refrigerated temperature (4 ± 2 °C)			Room temperature (20 ± 2 °C)		
		Control	Steamed	Irradiated	Control	Steamed	Irradiated
Colour	0	3.9 ay	3.2 bx	3.9 ax	–	–	–
	6	4.5 ax	3.2 cx	4.3 ax	3.7 b	1.9 d	2.9 c
Odour	0	3.6 ax	3.7 ax	3.0 bx	–	–	–
	6	3.3 abx	3.3 abx	3.1 abx	3.7 a	2.9 b	2.7 b
Pungent taste	0	3.2 ax	3.0 ax	3.1 ax	–	–	–
	6	3.4 ax	3.0 ax	3.2 ax	3.3 a	3.2 a	3.7 a
Overall acceptability	0	3.8 ax	3.4 abx	3.1 bx	–	–	–
	6	4.2 ax	3.1 bcx	3.6 bx	3.5 b	2.6 c	3.3 b

[a] Sensory evaluation was conducted by 15 panellists using a 5-point hedonic scale (5 = like very much; 1 = dislike very much for colour, odour and overall acceptability; and 5 = very strong; 1 = very weak for pungent taste). Means followed by the same letters within the row (a–c) and within the column per parameter (x–y) are not significantly different ($p < 0.05$).

3.5. Sensory attributes

Results of the sensory evaluation of red pepper powder showed a lower score in colour for the steamed red pepper than that of the control and irradiated ones (Table 5), indicating that the panellists had a lower likeness for the darker pepper. The colour score further decreased when the steamed pepper was stored at room temperature. The irradiated samples, on the other hand, exhibited lower colour values than the control ones only on the 6th month when stored at room temperature. The odour was slightly affected by irradiation but the difference in sensory scores among treatments disappeared after storage. However, for peppers stored at room temperature, both steamed and irradiated samples showed significantly lower odour scores than the control ones. Such a difference in odour may be due to the weakening of structural compounds or depolymerisation resulting in the disappearance of some volatiles in the pepper (Lee, Sung, Lee, & Kim, 2004). The pungent taste was not affected by either steaming or irradiation treatment. A slightly higher overall acceptability was observed for the untreated samples compared to steamed or irradiated ones. Storage time had no effect on the sensory properties of red pepper.

4. Conclusion

This comparative study demonstrated that gamma irradiation at 10 kGy was more effective than steaming treatment in their microbial decontamination effect on the powdered red pepper. Furthermore, steaming under high-temperature caused colour changes and lower sensory scores during storage at room temperature. However, the capsanthin content was lower in irradiated samples, while, the capsaicin content was not affected by both treatments. To minimise the changes in the physicochemical properties, refrigerated storage following irradiation is recommendable for the powdered red peppers.

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