pISSN 1225-4339 eISSN 2287-4992
Korean J. Food Nutr. Vol. 30. No. 2, 290~296 (2017)
https://doi.org/10.9799/ksfan.2017.30.2.290

THE KOREAN JOURNAL OF
한국식품영양학회지
FOOD AND NUTRITION

Effect of Surface Dielectric Barrier Discharge on the Physiological Activities of Quercetin

Hyun-Joo Kim[*], Hae In Yong[**], Sanghoo Park[***], Jooyoung Park[***], †Samooel Jung[****], Wonho Choe[***] and Cheorun Jo[**]

[*]*Crop Post-Harvest Technol. Division, Dept. of Central Area Crop Science, National Institute of Crop Science, RDA, Suwon 16613, Korea*
[**]*Dept. of Agricultural Biotechnology, Center for Food and Bioconvergence, and Research Institute of Agriculture and Life Science, Seoul National University, Seoul 16614, Korea*
[***]*Dept. of Physics, Korea Advanced Institute of Science and Technology, Daejeon 34141, Korea*
[****]*Dept. of Animal and Dairy Science, Chungnam National University, Daejeon 34143, Korea*

Abstract

In this study, using the surface dielectric barrier discharge (DBD) produced at atmospheric pressure to improve the physiological activities of quercetin was investigated. Quercetin (at 200 ppm) was treated using air DBD with an input power of 250 W. The tyrosinase inhibition effect and total phenolic content of quercetin increased from 38.96 to 91.58% and from 134.53 to 152.93 ppm, respectively, after 20 min of plasma treatment. The antioxidant activity of quercetin treated for 20 min in the lipid models was higher than that of quercetin treated for 0, 5, and 10 min. Furthermore, plasma-treated quercetin exhibited antimicrobial activity against *Listeria monocytogenes*, *Salmonella* Typhimurium, and *Staphylococcus aureus*, whereas activity was not shown in the control. Structural modifications of the quercetin molecule induced by plasma might be responsible for the improvements in its physiological activity. These results indicate that DBD plasma could be used to enhance the physiological activity of quercetin for various applications in food.

Key words: dielectric barrier discharge, atmospheric pressure plasma, quercetin, physiological activity

Introduction

Quercetin, one of the major dietary flavonoids, is widely distributed in plants and vegetables (Cook & Samman, 1996). Chemically, quercetin consists of two aromatic rings A and B linked by an oxygen-containing heterocycle (ring C). The multiple hydroxyl groups in the molecular structure of quercetin may play crucial roles in its widely demonstrated biological properties such as antioxidant, antiviral, and anticancer activities (Mendoza & Burd, 2011). However, the use of quercetin as a health-promoting agent has been limited by its poor bioavailability, which is caused by its low water solubility and high instability in neutral and alkaline media as well as in the small intestine, colon, liver, and kidney (Guo & Bruno, 2015). Many studies have proved that quercetin can bind with animal proteins such as bovine serum albumin (Fang et al., 2011), collagen (Yang et al., 2009), and β-casein (Mehranfar et al., 2013), which may promote the solubility, stability, and bioavailability of quercetin. However, these techniques are inefficient and costly.

Plasma generates various species including photons, electrons, positive and negative ions, and neutral particles as well as reactive species with sufficient energy to break covalent bonds and induce numerous chemical reactions (Laroussi M, 2002; Yong et al., 2015). Low-temperature atmospheric pressure plasmas have attracted increasing interest in a variety of applications. The operative and configuration conditions of atmospheric plasma generator inactivation have been extensively reviewed (Moreau et al., 2008). Reactive oxygen and nitrogen species produced by plasmas can cause peroxidation of lipids and oxidation of protein and DNA (Montie et al., 2000).

† Corresponding author: Samooel Jung, Dept. of Animal and Dairy Science, Chungnam National University, Daejeon 34143, Korea. Tel: +82-42-821-5774, Fax: +82-42-825-9754, E-mail: samooel@cnu.ac.kr

Recently, atmospheric pressure plasma has been continuously utilized and optimized for application in the food processing industries. The oxidative power of plasma was evaluated in order to preserve the qualitative characteristics of fresh-cut fruits and vegetables (Ramazzina et al., 2015), cheese (Yong et al., 2015), and raw meat (Jayasena et al., 2015). The technology also applied for meat curing process as nitrite source without external addition (Jung et al., 2015a; Jung et al., 2015b). In addition, dielectric barrier discharge (DBD) treatment improved the biological activity of naringin (Kim et al., 2014; Kim et al., 2015). In particular, preliminary data indicated that the water solubility index of quercetin was increased from 6.36 to 35.94% upon plasma treatment (data not shown). Therefore, the objective of this study was to evaluate the changes in the physiological activity of quercetin solution by encapsulated DBD at atmospheric pressure.

Materials and Methods

1. Sample and plasma treatment and visible emission spectrum

Quercetin was purchased from Sigma Co. (St. Louis, MO, USA). A 200 ppm quercetin solution in methanol was prepared for each experiment and diluted before use. The plasma apparatus was used by Kim et al. (2014). The DBD actuator, which consisted of strip electrodes and a 280 μm-thick polytetrafluoroethylene sheet, was installed in the inner wall of the airtight plastic container (137 × 104 × 53 mm^3). One electrode, which was buried as seen in Fig. 1, was connected to the power supply (bipolar square-waveform voltage at 15 kHz) while the 10 mm-wide electrode, spaced 5 mm apart, was grounded. The air surface discharge was generated inside the container with an input power of 250 W. Quercetin samples were placed in a glass dish at the bottom of the container and treated for 0, 5, 10, and 20 min. The visible emission spectrum of the discharge was obtained through spectrometers (Acton SP-750i) with the relevant optical setups.

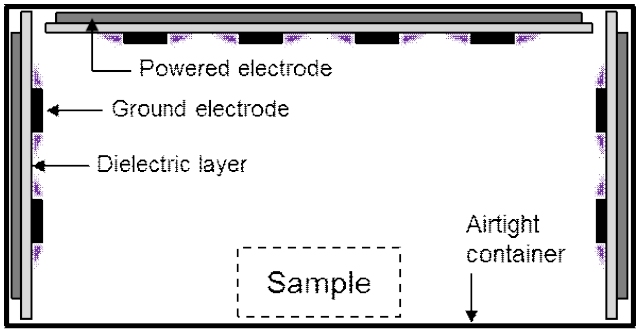

Fig. 1. Schematic cross-section of the DBD system for quercetin treatment.

2. Lipid oxidation

Oil emulsion was prepared for the 2-thiobarbituric acid reactive substances (TBARS) measurement. Soybean oil (1%) was homogenized (T10 basic, Ika Works, Germany) in double-distilled water (DDW) at 23,000 rpm for 2 min with 200 μL of quercetin solution. Tween 20 (100 μL) was added as an emulsifier. lipid oxidation was measured by TBARS using a spectrophotometer (X-ma 1000, Human Corp., Korea) (Jo et al., 2002). The TBARS values were expressed as micrograms of malondialdehyde per gram of sample.

3. Total phenolic content

The total phenolic content of the samples was estimated colorimetrically using the Folin-Ciocalteu method (Subramanian et al., 1965). Samples (0.1 mL) were added to the Folin-Ciocalteu reagent (0.2 mL), and 3 mL of 5% sodium carbonate solution was added. The reaction samples were mixed thoroughly by vortexing and after incubating the mixtures for 2 h at room temperature, the absorbance at 765 nm was measured using a spectrophotometer (X-ma 1000, Human Corp., Korea). The results were quantified based on a standard curve generated using gallic acid.

4. Tyrosinase inhibition effect

The tyrosinase inhibition effect was observed spectrophotometrically by monitoring the increase in the absorbance caused by the production of dopachrome from L-3,4-dihydroxyphenylalanine (L-DOPA) (Kim et al., 2014). Samples (0.2 mL) were added to 0.4 mL of the reaction mixture containing 10 mM L-DOPA (Sigma), 0.1 M potassium phosphate buffer (pH 6.8), and mushroom tyrosinase (100 U/mL, Sigma). Methanol was used as the control. The reaction mixture was incubated at 25℃ for 15 min. The amount of dopachrome produced in the reaction mixture was measured at 475 nm using a spectrophotometer (X-ma 1000, Human Corp., Korea). The tyrosinase inhibition effect (%) was calculated as follows:

$$\text{Tyrosinase inhibition effect (\%)} = [1 - (A_1/A_0)] \times 100$$

where A_0 is the absorbance of the control solution and A_1 is the absorbance of the sample.

5. Antimicrobial activity

1) Test microorganisms

Listeria monocytogenes (KCTC 3569), *Salmonella* Typhimurium (KCTC 1925), and *Staphylococcus aureus* (KCTC 1916) were obtained from the Korean Collection for Type Culture (KCTC, Daejeon, Korea). *S. aureus* was cultivated in tryptic soy broth. *L. monocytogenes* and *S.* Typhimurium were cultivated in tryptic soy broth containing 0.6% yeast extract and nutrient broth, respectively. Sterilized broths were inoculated using agar slant cultures of the microorganisms, and after incubating for 24 h at 37℃, 0.1 mL of culture was transferred to new broth and cultivated for 17 h. The cultures were centrifuged at 3,000 rpm for 15 min at 4℃ in a refrigerated centrifuge (UNION 32R, Hanil Science Industrial, Co., Ltd., Korea). Culture pellets were washed twice with sterile saline solution and the pellets were resuspended in sterile saline solution at a final cell density of 10^7 - 10^8 CFU/mL.

2) Paper disc diffusion assay

The antimicrobial activity was determined by the paper disc diffusion assay. Briefly, 0.1-mL aliquots of the test organisms were spread over the surface of agar plates. Sterilized filter-paper discs were saturated with 50 μL of each of the samples (filtered using 0.22-μm syringe filters) and incubated for 48 h, after which the diameters of the microbe-free clear zones around the disc on the culture plates were measured. The control sample was prepared using methanol.

6. High performance liquid chromatography (HPLC) analysis

An Agilent HPLC system 1100 equipped with a diode-array detector was used for the chromatographic separation of quercetin subjected to the plasma treatment. HPLC analysis was carried out on a YMC-Pack ODS A-302 column (4.6 mm i.d. × 150 mm; YMC Co., Ltd.) and was developed at 40℃ with 1% HCOOH/MeCN (82:18, flow rate: 1.0/min, detection: 254 nm).

7. Statistical analysis

Data were analyzed using SAS software (Release 8.01, SAS Institute, Inc., Cary, NC, USA). Statistical analysis was performed using one-way analysis of variance. When significant differences were detected, the differences among the mean values were determined by Duncan's multiple-comparison test at a confidence level of $p < 0.05$. Mean values and standard errors of the mean are reported.

Results and Discussion

1. Visible emission spectrum from the plasma

Optical emission spectrum of the DBD plasma obtained by optimal spectroscopy (SP2750, Princeton Instruments) is shown in Fig. 2. Due to the air discharge, strong nitrogen lines, $N_2(C^3\Pi_u$-$B^3\Pi g)$, N_2^+ $(B^2\Sigma_u^+$-$X2\Sigma g^+)$ and $NO_\gamma(A_2\Sigma^+$-$X_2\Pi)$, are observed. RONS such as N_2^+ and NO_γ, are considered to be responsible for quercetin activation.

2. Lipid oxidation and total phenolic content

The TBARS value of oil emulsion containing 200 μL of quercetin solution was higher than that of the control without quercetin added (Table 1). In particular, quercetin solution treated for 20 min has a significantly lower TBARS value than that of samples treated for 0, 5, and 10 min. Plasma treatment of quercetin decreased the lipid oxidation during storage. This phenomenon is explained by free radical production by molecules, which can be decreased by the treatment (Fornes et al., 1993). One of the most important components in natural substances is polyphenol. The content of total phenolic compounds in quercetin solution was 180.67 ppm. After quercetin was treated by DBD for 20 min, the concentration of phenolic contents increased to

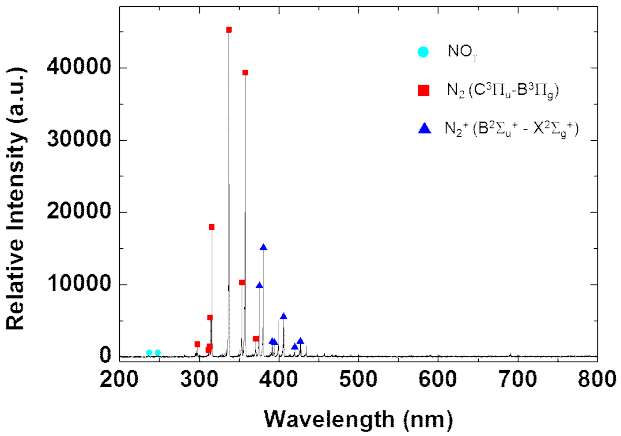

Fig. 2. A typical emission spectrum emitted by the air discharge plasma. NO, N_2, N_2^+molecular spectra were observed.

Table 1. 2-Thiobarbituric acid reactive substances (TBARS) values (μg malondialdehyde/g) of oil emulsion containing plasma-treated quercetin during storage at 37℃

Treatment time (min)	Storage time (hr)			SEM[1)]
	0	1.5	3	
Methanol	0.59^{b}	0.85^{bx}	1.34^{ax}	0.086
0	0.59^{b}	0.71^{bxy}	1.30^{axy}	0.058
5	0.58^{c}	0.72^{bxy}	1.19^{axyz}	0.026
10	0.58^{b}	0.63^{by}	1.03^{ayz}	0.041
20	0.60^{b}	0.58p	0.94^{az}	0.058
SEM[2)]	0.010	0.053	0.083	

[1)] Standard error of the mean (n=9), [2)](n=15)

[a~c] Values with different letters within the same row differ significantly (p<0.05)

[x~z] Values with different letters within the same column differ significantly (p<0.05)

195.17 ppm (Table 2). The increase in phenolic content is consistent with the result reported by previous study (Kim et al., 2014).

Various studies have reported a correlation between phenolic content and antioxidant activity. Liu et al. (2012) determined that UV-C irradiation tended to increase the antioxidant activity and phenolics of quercetin in tomato fruits. Fan et al. (2003) showed that the phenolic content and antioxidant activity in lettuce exhibited a high response to irradiation.

The increased total phenolic content could be attributed to the release of phenolic compounds from the glycosidic components and the degradation of larger phenolic compounds into smaller ones by irradiation, with a consequent improvement in the extraction yield of the phenolic compounds as a result of the change in the tissue structure of samples by irradiation (Choi et al., 2009; Yang et al., 2012). Another reason for the increase by plasma treatment might be the breakage of multimeric polyphenols. It had been reported that water molecules were dissociated into hydroxyl radicals and peroxides by plasma treatment. These radicals easily broke the glycosidic bonds and covalent linkage in the large molecules and made smaller ones (Choi et al., 2010). Recently, Kim et al. (2015) showed that the new flavanone glycoside, narinplasmin A, containing a methoxyalkyl group exhibited significantly improved antioxidant properties of naringin with DBD.

Table 2. Total phenolic content and tyrosinase inhibition effect of quercetin treated by plasma

Treatment time (min)	Total phenolic content (ppm)	Tyrosinase inhibition effect (%)
0	180.67^{a}	12.49^{a}
5	182.33^{ab}	29.91^{b}
10	185.00^{b}	53.18^{c}
20	195.17^{c}	78.34^{d}
SEM[1)]	0.050	0.104

[1)] Standard error of the mean (n=12)

[a~d] Values with different letters within the same column differ significantly (p<0.05)

3. Tyrosinase inhibition effect

Because tyrosinase is responsible for the biosynthesis of pigment melanin in human skin, tyrosinase inhibition effect is an important standard for the application in the cosmetics industry due to its skin-whitening effect (Wu & Park, 2003). The original tyrosinase inhibition effect of quercetin was 12.49%, and increased to 78.34% after DBD plasma treatment for 20 min (Table 2). Kim et al. (2015) also demonstrated that the tyrosinase inhibition effect of naringin increased from 6.12% to 83.30% upon plasma treatment.

Other results for the tyrosinase inhibition effect were reported in Japanese honeysuckle and green tea byproducts treated by irradiation (Byun et al., 2004; Lee et al., 2006). Phenolic compounds, such as flavonoids, tannins and lignin, are mainly responsible for the tyrosinase inhibition (Kim et al., 2009). Based on our earlier results of flavonoid content, increased tyrosinase inhibition could be due to increased levels of flavonoids derived from the breakdown of Cya-3-O-xylrut that particularly affects tyrosinase inhibition levels (Lee et al., 2011).

4. Antimicrobial effect

The growth inhibition zones of quercetin treated by plasma against foodborne pathogens were evaluated, as shown in Table 3. Results were obtained from the disc diffusion method. Quercetin did not initially exhibit any antimicrobial activity; however, antimicrobial activity was increased with increasing plasma treatment time. The diameters of clear zones were 24, 21, and 15 mm against *S.* Typhimurium, *S. aureus*, and *L. monocytogenes*, respectively, after 20 min of plasma treatment of quercetin. Kim et al. (2015) showed that naringin treated with DBD exhibited antimicrobial activity against foodborne pathogens, especially *S.* Typhimurium. Phenolics were the most important active compounds against bacteria control (Shoko et al., 1999). The chemi-

Table 3. Antimicrobial activity of quercetin of treated by plasma, measured using the paper diffusion method

Pathogens	Diameter (mm)				
	Methanol	0 min	5 min	10 min	20 min
Salmonella Typhimurium	-[1)]	-	-	16[2)]	24
Listeria monocytogenes	-	-	-	12	15
Staphylococcus aureus	-	-	-	-	21

[1)] No inhibition.
[2)] Clear-zone diameter (disc diameter=8 mm)

cal structure of irradiated phenolics might not have changed, but the activity of the functional groups, such as −OH or −COOH, may change, resulting in higher antimicrobial activity (An et al., 2004).

5. HPLC analysis

The HPLC chromatograms of quercetin before and after plasma treatment (Fig. 3) showed that plasma treatment degraded quercetin, and that the degradation rate and extent increased when the treatment time was extended to 20 min. Considering the peak area of non-treated quercetin to be 100%, only 33.37% of quercetin was present after plasma treatment for 20 min, where as 5 new peaks were detected except for peak area of < 1% (Table 4). This phenomenon implies that quercetin is physically/chemically trapped by other components.

Bactericidal agents in plasmas are known to contain reactive oxygen species (ROS), UV photons, energetic ions, and electrons. The ROS generated by air-based plasmas have been identified as ozone, atomic oxygen, superoxide, peroxide, and hydroxyl radicals (Gaunt et al., 2006). Yang et al. (2012) showed that the ROS and molecules produced by irradiation are obviously capable of producing soluble quercetin, resulting in a high extraction efficiency of all phenolic compounds in onion.

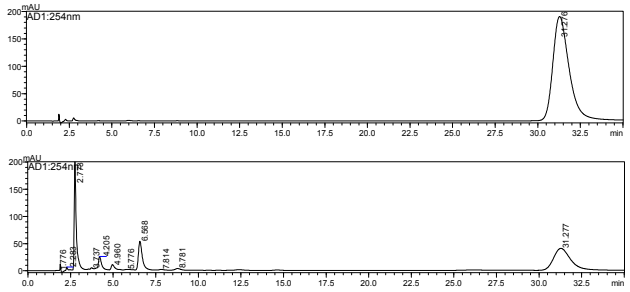

Fig. 3. HPLC chromatograms of quercetin treated by plasma. (a) control, (b) sample treated for 20 min.

Table 4. Relative peak area percentage of compounds generated from quercetin after plasma treatment.

Retention time (min)	Peak area (%)
2.778	29.03
4.205	4.52
4.960	2.36
6.568	14.35
8.781	1.2
31.277	48.54
Total	100

Conclusion

Form the results, the physiological activities of quercetin including its antioxidant activity, tyrosinase inhibition effect, and antimicrobial activity can be improved by air DBD. Recent studies revealed that plasma-treated chicken breast and plasma-cured sausage did not show genotoxicity (Lee et al., 2016) and immune toxicity (Kim et al., 2016), respectively. These results indicate that quercetin activated by atmospheric pressure plasmas could be used as a functional material for various applications in food.

Acknowledgment

This work was supported by R&D Program (Plasma Farming, Project No. EN1425-1) through the National Fusion Research Institute (NFRI) of Korea funded by the Government funds.

References

An BJ, Kwak JH, Son JH, Park JM, Lee JY, Jo C, Byun MW. 2004. Biological and anti-microbial activity of irradiated green tea polyphenols. *Food Chem* 88:549-555

Byun MW, Jo C, Jeon T, Hong CH. 2004. Effects of gamma irradiation on colour characteristics and biological activities of extracts of *Lonicera japonica* (Japanese honey suckle) with methanol and acetone. *LWT-Food Sci Technol* 37: 29-33

Choi J, Kim HJ, Kim JH, Song BS, Chun BS, Ahn DH, Byun MW, Lee JW. 2009. Improvement of color and physiological properties of tuna-processing by-product by gamma irradiation.

Radiat Phys Chem 78:601-603

Choi J, Kim HJ, Kim JH, Chun BS, Ahn DH, Kim GH, Lee JW. 2010. Changes in colour and antioxidant activities of *Hizikia fusiformis* cooking drips by gamma irradiation. *LWT-Food Sci Technol* 43:1074-1078

Cook NC, Samman S. 1996. Flavonoids- Chemistry, metabolism, cardioprotective effects, and dietary sources. *J Nutr Biochem* 7:66-76

Fan X, Toivonen PMA, Rajkowski KT, Sokorai KJB. 2003. Warm water treatment in combination with modified atmosphere packaging reduces undesirable effects of irradiation on the quality of fresh-cut iceberg lettuce. *J Agric Food Chem* 51:1231-1236

Fang R, Hao R, Wu X, Li Q, Leng X, Jing H. 2011. Bovine serum albumin nanoparticle promotes the stability of quercetin in simulated intestinal fluid. *J Agric Food Chem* 59: 6292-6298

Fornes M, Barbieri A, Burgos M. 1993. Spem motility loss induced by gossypol: relation with OH scavengers, motile stimulators and malondialdehyde production. *Biochem Biophys Res Commun* 195:1289-1293

Gaunt LF, Beggs CB, Georghiou GE. 2006. Bactericidal action of the reactive species produced by gas-discharge nonthermal plasma at atmospheric pressure: A review. *IEEE T Plasma Sci* 34:1257-1269

Guo Y, Bruno RS. 2015. Endogenous and exogenous mediators of quercetin bioavailability. *J Nutr Biochem* 26:201-210

Jayasena DD, Kim HJ, Yong HI, Park S, Kim K, Choe W, Jo C. 2015. Flexible thin-layer dielectric barrier discharge plasma treatment of pork butt and beef loin: Effects of pathogen inactivation and meat quality attributes. *Food Microbiol* 46: 51-57

Jo C, Ahn HJ, Son JH, Lee JW, Byun MW. 2002. Packaging effect on residual nitrite content and nitrosamine formation in irradiated cooked pork sausage. *Food Control* 14:7-12

Jung S, Kim H J, Park S, Yong HI, Choe JH, Jeon HJ, Choe W, Jo C. 2015a. The use of atmospheric plasma-treated water as a source of nitrite for emulsion-type sausage. *Meat Sci* 108:132-137

Jung S, Kim HJ, Park S, Yong HI, Choe JH, Jeon HJ, Choe W, Jo C. 2015b. Color developing capacity of plasma-treated water as a source of nitrite for meat curing. *Korean J Food Sci An* 35:703-706

Kim HJ, Choi J, Kim DJ, Kim JH, Chun BS, Ahn DH, Yook HS, Byun MW, Kim MJ, Shin MG, Lee JW. 2009. Effect of ionizing radiation on the physiological activities of ethanol extract from *Hizikia fusiformis* cooking drips. *Appl Radiat Isotopes* 67:1509-1512

Kim HJ, Sung NY, Yong HI, Kim H, Lim Y, Ko KH, Yun C, Jo C. 2016. Mutagenicity and immune toxicity of emulsion-type sausage cured with plasma-treated water. *Korean J Food Sci An* 36:494-498

Kim HJ, Yong HI, Park S, Kim K, Kim TH, Choe W, Jo C. 2014. Effect of atmospheric pressure dielectric barrier discharge plasma on the biological activity of naringin. *Food Chem* 160:241-245

Kim TH, Jang SJ, Chung HW, Kim HJ, Yong HI., Choe W, Jo C. 2015. Enhancement of antioxidant effects of naringin after atmospheric pressure dielectric barrier discharge plasma treatment. *Bioorg Med Chem Lett* 25:1236-1239

Laroussi M. 2002. Nonthermal decontamination of biological media by atmospheric-pressure plasmas: review, analysis, and prospects. *IEEE T Plasma Sci* 30:1409-1415

Lee H, Yong HI, Kim HJ, Choe W, Yoo SJ, Jang EJ, Jo C. 2016. Evaluation of the microbiological safety, quality changes, and genotoxicity of chicken breast treated with flexible thin-layer dielectric barrier discharge plasma. *Food Sci Biotechnol* 25:1189-1195

Lee NY, Jo C, Sohn SH, Kim JK, Byun MW. 2006. Effects of gamma irradiation on the biological activity of green tea by-product extracts and a comparison with green tea leef extracts. *J Food Sci* 71:C269-C274

Lee SS, Lee EM, An BC, Kim TH, Lee KS, Cho JY, Yoo SH, Bae JS, Chung BY. 2011. Effects of irradiation on decolourisation and biological activity in *Schizandra chinensis* extracts. *Food Chem* 125:214-220

Liu C, Cai L, Lu X, Han X, Ying T. 2012. Effect of postharvest UV-C irradiation on phenolic compound content and antioxidant activity of tomato fruit during storage. *J Integr Agric* 11:159-165

Mehranfar F, Bordbar AK, Parastar H. 2013. A combined spectroscopic, molecular docking and molecular dynamic simulation study on the interaction of quercetin with beta-casein nanoparticles. *J Photochem Photobiol B* 127:100-107

Mendoza EE, Burd R. 2011. Quercetin as a systemic chemopreventative agent: Structural and functional mechanisms. *Mini Rev Med Chem* 11:1216-1221

Montie TC, Kelly-Wintenberg K, Roth JR. 2000. An overview of

research using the one atmosphere uniform glow discharge plasma (OAUGDP) for sterilization of surfaces and materials. *IEEE T Plasma Sci* 28:41-50

Moreau M, Orange N, Feuilloley MGJ. 2008. Non-thermal plasma technologies: new tools for bio-decontamination. *Biotechnol Adv* 26:610-617

Ramazzina I, Beradinelli A, Rizzi F, Tappi S, Ragni L, Sacchetti G, Rocculi P. 2015. Effect of cold plasma treatment on physico-chemical parameters and antioxidant activity of minimally processed kiwifruit. *Postharvest Biol Technol* 107: 55-65

Shoko T, Soichi T, Megumi MM, Eri F, Jun K, Michiko W. 1999. Isolation and identification of an antibacterial compounds from grape and its application to food. *Nippon Nogeikagaku Kaishi* 73:125-128

Subramanian KN, Padmanaban G, Sarma PS. 1965. Folin-Ciocalteu reagent for the estimation of siderochromes. *Analy Biochem* 12:106-112

Wu H, Park HY. 2003. Protein kinase C-β-mediated complex formation between tyrosinase and TRP-1. *Biochem Biophys Res Commun* 311:948-953

Yang EI, Lee EM, Kim YS, Chung BY. 2012. The role of gamma irradiation on the extraction of phenolic compounds in onion (*Allium cepa* L.). *Radiat Phys Chem* 81:1025-1028.

Yang X, Wu D, Du Z, Li R, Chen X, Li X. 2009. Spectroscopy study on the interaction of quercetin with collagen. *J Agric Food Chem* 57:3431-3435

Yong HI, Kim HJ, Park S, Alahakoon AU, Kim K, Choe W, Jo C. 2015. Evaluation of pathogen inactivation on sliced cheese induced by encapsulated atmospheric pressure dielectric barrier discharge plasma. *Food Microbiol* 46:46-50

Received 03 January, 2017
Revised 13 March, 2017
Accepted 21 March, 2017