



Effect of Radio Frequency Heating on Physical and Biochemical Parameters of Black Pepper Powder

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ABSTRACT

The effect of radio-frequency (RF) heating on quality parameters of powdered black pepper spice was investigated. Black pepper powder was treated with RF energy to achieve 70° C average temperature maintained for 15 minutes. There was no significant difference in colour, water activity and piperine content of RF-treated and untreated black pepper powder. The essential oil extracted from the treated and untreated black pepper powder was 0.52 g and 0.55 g, respectively. Total phenolic contents of black pepper essential oil were 0.29±0.02 mg GAE. g⁻¹ oil for untreated sample and 0.30±0.02 for RF-treated sample. The results suggested that RF heating can be effectively used for black pepper powder without significant changes in its physical and biochemical parameters.

Radio frequency (RF), an electromagnetic wave with a frequency range of 3 kHz to 300 MHz, is a promising technology for heating food applications because of the associated rapid and uniform heat distribution, large penetration depth and lower energy consumption. It forms a part of innovative techniques based on electromagnetic heating, where the electrical energy is converted to electromagnetic radiation, which subsequently generates heat within the product. During RF heating, the heat is generated within the product due to molecular friction resulting from oscillating molecules and ions caused by the applied alternating electric field.

The US Federal Communications Commission (FCC) allocated 13.56, 27.12 and 40.68 MHz in the RF range for industrial, scientific and medical (ISM) application (Kimber *et al.*, 2012). Radio frequency heating has been successfully applied for drying, baking and thawing of frozen meat and in meat processing. However, its use in continuous pasteurization and sterilization of foods is rather limited (Tiwari *et al.*, 2011).

Spices have been used as flavouring and seasoning

agents in foods. However, they are of natural origin and may be burdened with high levels of moulds, yeasts, and bacteria (Rico *et al.*, 2010). Contaminated spices can lead to a rapid spoilage of foods and serious food borne illness when they are added to foods that do not undergo further cooking (Waje *et al.*, 2008; Rico *et al.*, 2010). In 2009, a multistate outbreak of *Salmonella Montevideo* infection occurred in USA, which was traced in salami products made with contaminated black and red pepper spice. By the end of April 2010, it was reported that 272 persons in 44 states had become ill due to the outbreak (Anon., 2010).

Black pepper (*Piper nigrum* L.), also called as the 'King of Spices', shares a prominent place on most dinner tables next to salt. Black pepper is a common spice produced in oriental countries (mostly in south east Asia including India, Indonesia and Malaysia), but is used worldwide for its characteristic pungent flavour and taste. The chemical composition of black pepper consists of moisture (8.7-14.1%), total nitrogen (1.6-2.6%), nitrogen in non-volatile ether extract (2.7-4.2%), volatile ether extract (4.4-12.0%), starch by acid hydrolysis (28.0-49.0%), crude fibre (8.7-18.0%),

crude piperine (2.8-9.0%), piperine (1.7-7.4%), total ash (3.6-5.7%), and acid insoluble ash (0.03-0.6%) (Megwal and Goswami, 2012).

The characteristic aromatic odour of pepper is due to the presence of volatile oils in the cells of the pericarp. Many spices, including black pepper, are ground to coarse or fine particles to provide convenience for human consumption. Several decontamination methods such as fumigation with ethylene oxide, irradiation, and steam treatment have been developed to reduce the microbial loads of spices. However, use of ethylene oxide, generally regarded as a carcinogen, is restricted and even banned in the European Union. Although irradiation is allowed for the decontamination of dried spices in many countries, it has not found acceptance by the consumer (Farkas, 2006; Schweiggert *et al.*, 2007). Waje *et al.* (2008) reported that commercial steam treatment at 1020 mbar and 100 °C for 16 min of black pepper led to quality deterioration with significant loss of colour and flavour. Accordingly, there is a need for the development of innovative technologies for disinfecting spices while maintaining their quality.

Radio-frequency heating in food processing offers the possibility to replace the conventional method of heat processing (Pereira and Vicente, 2010). There have been several researches on RF heating as a new thermal treatment method for nuts (Gao *et al.*, 2010; Gao *et al.*, 2011; Wang *et al.*, 2001) and fruits (Birla *et al.*, 2018). Thus, RF heating has the potential for fast heating in solid and semi-solid foods which have low thermal conductivities (Casal *et al.*, 2010). RF heating offers advantages of more uniform heating than microwave due to its lower frequencies (13.56, 27.12, and 40.68 MHz) and deeper penetration depth (200-250 mm) compared with those of microwaves (20-50 mm) at 915 or 2450 MHz (Marra *et al.*, 2009).

RF technology could be an alternative to the traditional (water and steam) and microwave heating in food processing. In current scenario, RF heating is being the preferred method in modern industries for product cooking, baking, drying, pasteurization and other applications (Jojo and Mahendran, 2013).

In view of the above facts, the present study on the effect of RF heating on physical and biochemical characteristics of black pepper powder was undertaken.

MATERIALS AND METHODS

Sample Preparation

The experiments were carried out in the Department of Processing and Food Engineering, College of Agricultural Engineering, University of Agricultural Sciences, Raichur (Karnataka).

Commercially dried black pepper powder (5.0 kg) was procured from local grocery market of Raichur, Karnataka. The size of the black pepper powder was determined by using a sieve analyzer, and particles passing through 60 mesh were used for further studies. The properties of black pepper powder (*viz.*, moisture content, bulk and tapped density, colour, water activity) were measured for untreated and RF-treated samples. Further, the biochemical constituents of black pepper powder (*viz.*, piperine content, essential oils, total phenolics and DPPH radical scavenging activity) were measured after RF treatment, and compared with the untreated sample.

Physico-chemical Analysis of Black Pepper Powder

Moisture content

Moisture content of untreated and RF-treated black pepper powder was determined by toluene distillation method. The equipment consisting of a 500 ml round bottom flask with T.S. 24 by 19 joint, West condenser with a drip tip of 400 mm length, Dean and Stark water estimation trap (10 ml capacity, graduated in 0.1 ml interval), an electric heating mantle with variable power control was used. An analytical balance (Sensitivity: (\pm) 0.01g) was used. Sample of 40 g of black pepper powder was transferred to the distillation flask, and sufficient quantity of toluene was added to cover the sample along with boiling chips. A loose non-absorbing cotton plug was inserted in the top of the condenser to prevent condensation atmospheric moisture into the condenser. The mixture of toluene and sample were brought to boiling condition, and reflux was set to two drops per second until all water was collected in the trap. Refluxing was continued until two consecutive readings showed no change (AOAC, 2005; Method 986.21).

Bulk and Tapped Density

Bulk and tapped density of black pepper powder were determined by measuring the volume of a known mass of powder sample in a measuring vessel (He *et al.*, 2018). Approximately 100 g of the powder with particle

size greater than or equal to 1 mm, gently filled in to the graduated cylinder of 250 ml without compacting, carefully leveled, and read the unsettled apparent volume (V) to the nearest graduation. The bulk density was calculated by dividing the mass by volume(V).

Tapped density was determined by mechanically tapping the graduated cylinder until little further volume (V1) change was observed. Tapped density was calculated using the ratio of mass by volume (V1).

Water activity

Water activity (a_w) of untreated and RF-treated sample was measured using Aqua lab Vapour Sorption Analyzer (Water activity range: Dew point block (-) 0.05 to 1.00; Accuracy: (\pm) 0.01 a_w , Volatile block: (-) 0.05 to 0.95 a_w ; Operating environment: 4 to 50 °C; Relative humidity: 0 to 90%). The principle used was chilled-mirror dew point technique to determine the water activity. Black pepper powder was placed in the sample cup, and the drawer was closed. The knob was turned on to read position to seal the sample cup with the chamber. The water activity value was displayed on the LED flash with a beep.

Colour

Hunters lab colorimeter was used to measure the colour changes of RF-treated black pepper powder sample. The colorimeter has port size of 31.8 x 14.30 mm with a spectral range of 400 – 700 nm and display screen of 6.4 x 6.4 cm. Colour was measured by using CIELAB scale at 10° observers with D_{65} illuminant. It works on the principle of focusing the light and measuring the energy reflected from the sample across the entire visible spectrum. The values of L^* , a^* , and b^* , indicating colour lightness, redness, and yellowness of a sample.

Radio Frequency Heating System

A RF dielectric heating system with a pilot scale RF heater of 6 kW and 27.12 MHz (SO-6B, Monga Strayfield, Pvt Ltd, India) was used for heating black pepper powder (Fig. 1). The size of the flat plate top electrode in the RF heater was 830 mm × 400 mm, and the bottom electrode was 990 mm × 590 mm. Black pepper powder sample was contained in a RF transparent polycarbonate sample holder (diamter: 190 mm, height: 25 mm), and placed in between the two electrodes. The applicator housed in a metallic enclosure, the gap between the electrodes was



Fig. 1: Pilot-scale 6 kW, 27.12 MHz RF unit showing the two-pair plate electrodes

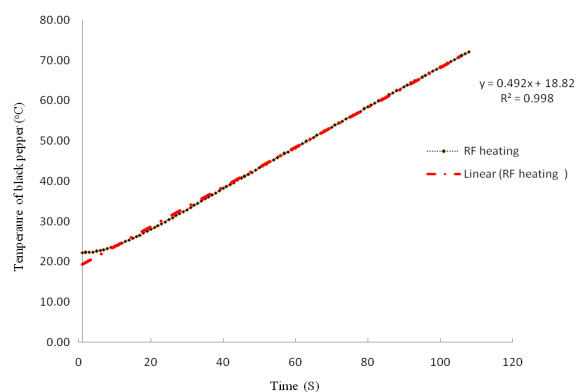


Fig. 2: Temperature rise in black pepper powder during RF heating

adjusted (100 -105 mm) to change RF power coupled to a sample. The sample temperatures (T) at specific locations (surface, middle and bottom of the sample) were sensed using e3 fibre optic temperature sensors. The data acquisition programme (Neoptix Optilink Software) continuously acquired the temperature, anode current and grid current displayed at 30 s time interval on a digital display (accuracy: 0.8°C). The fibre optic temperature sensor (Neoptix Reflex) is a table top multi-purpose fibre optic temperature thermometer with 4 channels. The sensor had interface with RS-232 communication system. The probes had immunity to electromagnetic interference and harsh environments and perform better traditional sensors.

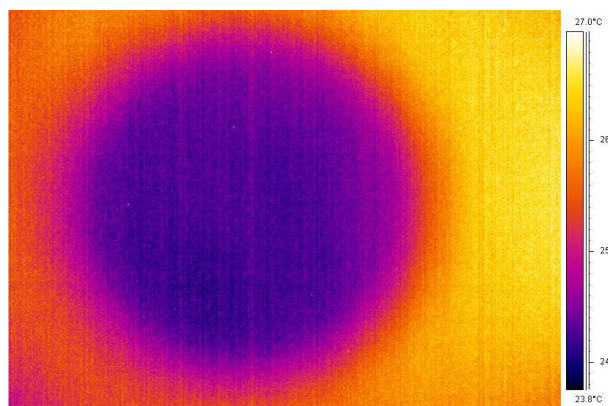
Black pepper powder (500 g) was placed in a sample holder and subject to RF heating for 108 seconds to rise its temperature to 70°C. The sample was then immediately transferred to a hot air oven (MAC-WSDA-12) maintained at 70°C to continue the treatment for 15 minutes. The average temperatures

at the centre and periphery of powder sample were measured before and after RF treatment using an infrared thermal imaging camera. The IR thermal Imaging Camera (FLIR-C2) worked in the range of $(-10^{\circ}\text{C}$ to $(+150^{\circ}\text{C}$ with focal length of 1.54 mm and accuracy of $(\pm) 2^{\circ}\text{C}$.

Thermal treatment was selected based on the study of Farag *et al.* (1996) for different spices *viz.*, black pepper, fennel, coriander and rhizome of turmeric. The authors had stated that the use of thermal treatment at 70°C for 15 min served as heat shock, and reduced the bacterial and fungal counts by about 3-4 log cycle beside decreasing the total aerobic thermophiles and other pathogenic microbes in spices. Average temperatures of core and perimeter of black pepper powder during treatment with 27.12 MHz. RF energy were measured using a thermal imaging camera, and the images are depicted in Figs. 3 and 4.

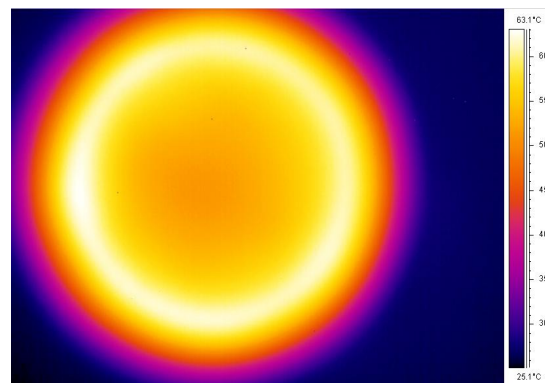
Piperine Extraction and Analysis

A sample of 0.1 g black pepper in 100 ml ethanol was magnetically stirred overnight using a magnetic stirrer (PCE-MSR-150, suitable for volumes up to 10 l, adjustable speed range of 200 - 2200 rpm with speed changes in steps of 10 rpm, speed accuracy: $(\pm) 20$ rpm). The suspension was filtered, and the piperine in the filtrate was determined by a high-performance Liquid Chromatograph (Waters-2695) with a fluorescence detector. Thermo Scientific C18 (250×4.6 mm, 5μ) column was the stationary phase. Isocratic elution was performed with mobile phase of 50% of acetonitrile and 50% water. The flow rate was $1.0\text{ ml}\cdot\text{min}^{-1}$ and detection wavelength was at 341 nm. The $10\ \mu\text{l}$ portion of black pepper ethanol filtrate was injected into column using



(Blue circle at centre indicate black pepper powder at 24°C)

Fig. 3: Surface temperature profile of black pepper powder before RF treatment



(Yellow circle at centre indicate black pepper powder at 60°C , and decrease in temperature towards periphery)

Fig. 4: Surface temperature profile of black pepper powder after RF

an automatic injector. Standard piperine (M/S Alfa Aesar, 98% purity) and standard piperine solutions between 15.62 - $125.0\ \mu\text{g}\cdot\text{ml}^{-1}$ were prepared in ethanol.

Black Pepper Essential Oil

Among the components, piperine existing mostly in the essential oil of black pepper, is responsible for the pungency properties. Piperine is a bioactive constituent and plays an important role in soothing muscular aches and pains, relieving digestion issues, and healing respiratory infections. The α - and β -pinene, limonene, myrcene, linalool, α -phellandrene, sabinene, β -caryophyllene, and germacrene-D are responsible for flavour and aroma. The essential oil of black pepper also finds use in the food and beverage industries, and in cosmetics as well (Tran *et al.*, 2019).

Black pepper essential oil (*Piper nigrum*) was distilled from the berries (peppercorn) of the Piperaceae.

Extraction of essential oil

Black pepper powder was hydro-distilled for 4 h by using a Clevenger type apparatus (Borosil -1000 ml).

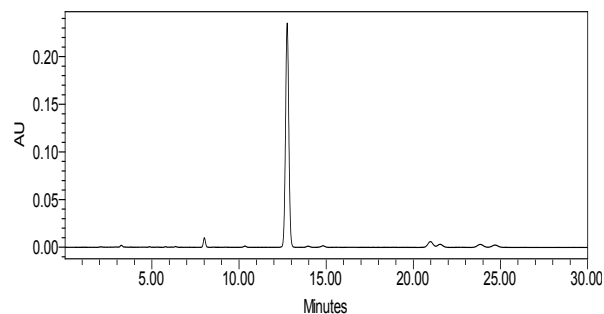


Fig. 5: HPLC separation profile of piperine in untreated black pepper powder

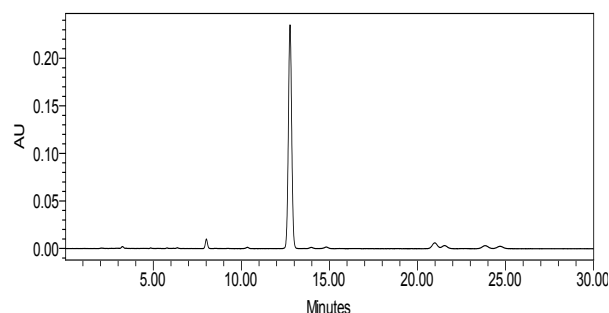


Fig. 6: HPLC separation profile of piperine in RF-treated black pepper powder

The apparatus contained a 1,000-ml flask, a condenser, and a measuring tube with stopcock. The oils (~0.53 g oil) collected from distillation of 34 g of black pepper powder in presence of 400 ml distilled water were protected from light by covering with aluminium foil, and stored at 4 °C for a maximum period of 7 days till being used in the analysis.

Determination of essential oil composition

The compositions of black pepper essential oils were determined by a Hewlett Packard 5890 Series Gas Chromatograph and 5972 Series Mass Selective Detector (GC-MS). HP 5890 Series II Gas Chromatograph is equipped with a stand-alone capillary gas chromatograph detector to enhance procedure performance. The mass selective detector, equipped with a monolithic hyperbolic quartz quadrupole mass filter, a quick-change electron multiplier, a high efficiency electron impact ion source, and a high reliability vacuum system, combines the features of gas-liquid chromatography and mass spectrometry to identify different substances of a test sample. The column was Hewlett Packard DB1 (100% dimethyl polysiloxane) capillary column. The oven temperature used was from 50 °C to 240 °C with 4 °C.min⁻¹ heating rate, with the temperature of 240°C maintained for 5 min. The ionization energy was 70 eV and mass range were 40-400 amu. The oil was diluted with hexane (1:100), and 1 µl of diluted sample was injected into GC-MS with 1:20 split ratio. Solvent delay was 3.5 min. The compositions of the samples were identified by NBS75K.L mass spectral library.

Determination of total phenols

Total phenolic content of black pepper oil was analysed by a Folin-Ciocalteu assay (Magulska and Wesolowsk, 2018). Black pepper essential oils were diluted with ethanol, and the oil solution was mixed with 2 ml diluted Folin-Ciocalteu reagent. After

10 min, 1.6 ml of 7.5% Na₂CO₃ was added. The mixture was stirred and kept at ambient temperature for 2 h. Absorbance at 765 nm was recorded using a spectrophotometer (Beckman, DU-520, measures absorbance and transmittance over entire UV-Vis range of 190 nm to 1100 (+/-) 1 nm; spectral bandwidth: <4.5 nm). With RS-232. A calibration curve was prepared using gallic acid standards at 0.50-4.00 µg.ml⁻¹ assay solutions. Total phenolic acids in the extracts were expressed as gallic acid equivalents (GAE).

Determination of DPPH radical scavenging activity

The ethanolic solutions of black pepper essential oil at various concentrations were mixed with 2 ml of 0.003 g.100 ml⁻¹ DPPH solution in ethanol. The decrease in absorbance at 517 nm was determined with a spectrophotometer (Beckman, DU5-20) after 15 min. Ethanol was used as blank. The control was DPPH solution without oil control. Scavenging activity was determined based on the percentage of DPPH radical scavenged as:

$$\text{Scavenging effect (\%)} = \frac{[(\text{Control absorbance} - \text{Sample absorbance}) / (\text{Control absorbance})] \times 100}{1}$$

Statistical Analysis

For all determinations, five replicates of sample were done. ANOVA (Analysis of Variance), single factor, was used at significance level of 0.01 for analysis of results.

RESULTS AND DISCUSSION

Quality Analysis of Black Pepper Powder

The quality of black pepper powder before and after RF treatment was assessed in terms of its moisture content, water activity (aw), colour, piperine content, total phenolics, antioxidant activity and volatile compounds. The results are presented in Table 1.

Moisture Content and Water Activity

From Table 1, it is seen that the moisture content of black pepper powder decreased from initial value of 9.67±0.02% to 8.45±0.10% (w.b.) during the RF treatment; while the water activity (aw) reduced from 0.64 to 0.42. The reduction in both parameters might be due to water loss from the powder during thermal treatment by RF energy. In RF heating, the heat is generated within the product due to the friction resulting from oscillating molecules and ions caused by the applied alternating electric field. Similar results

of reduction in moisture content and water activity were observed for black and red pepper subjected to RF heating (Jeong and Kang, 2014). The rise in the temperature of powder from its initial value of 24 °C to 70 °C during RF heating for period of 108 s is depicted in Fig. 2. The images of the powder sample before and after RF treatment obtained from IR thermal imaging camera are presented in Fig. 3 and 4. These thermal images exhibited greater uniformity in temperature across the profile of the black pepper powder sample.

Bulk and Tapped Density

The average bulk density and tapped density of black pepper powder was found to be 0.52 ± 0.02 and $0.48 \pm 0.15 \text{ g.ml}^{-3}$ and 0.64 ± 0.02 and $0.59 \pm 0.02 \text{ g.ml}^{-3}$, respectively. The decrease in the bulk and tapped density is due to the reduction in moisture content of powder after RF treatment.

Colour

From Table 1, it is observed that the RF treatment changed the colour values (L^* , a^* and b^*) from 50.2 ± 0.01 , 3.1 ± 0.05 and 12.4 ± 0.32 to 48.2 ± 0.05 , 3.3 ± 0.03 and 13.1 ± 0.03 , respectively. There was no significant change in the colour of the pepper powder after RF treatment. The small changes in the colour values might be due to shorter period of RF treatment, resulting in minimum thermal degradation of its constituents. Similar findings have been reported by Ha *et al.* (2013) for peanut butter crackers. Geveke *et al.* (2007) had reported RF heating caused insignificant changes in enzymatic browning in orange juice with no loss in ascorbic acid content.

Piperine content

The piperine content in the untreated and RF-treated black pepper powder was found to be $50.07 \pm 1.60 \text{ mg.g}^{-1}$ and $49.38 \pm 2.93 \text{ mg.g}^{-1}$, respectively. There was no significant difference in the piperine content of RF-treated and untreated black pepper powder.

The HPLC separation profile indicated similar peaks of piperine content in the samples before and after RF treatment as depicted in Fig. 5 and Fig. 6. The minute variation in the piperine content proved minimum thermal degradation of piperine due to RF treatment. The results are in confirmation with the findings of Skapska *et al.* (2003) for piperine content in black pepper treated with high pressure (100 MPa) and temperature (140 °C).

Total phenolic content

Total phenolic contents in black pepper essential oil before and after RF treatment were found to be 2.7 ± 0.01 and $2.9 \pm 0.20 \text{ mg of GAE.g}^{-1}$ of oil, respectively. It was noticed that there was no significant difference in total phenolic content due to RF treatment. The minor increase in the total phenolic content of pepper powder might be due to cell disruption in peppers, and also ionization of active molecules during RF heating. The results are in line with the findings of Zarai *et al.* (2013) for *Ricinus communis* L. essential oil and Andrade and Ferreira (2013) for black pepper essential oil.

DPPH radical scavenging activity

DPPH radical scavenging activity of black pepper essential oil in samples before and after RF treatment was

Table 1. Quality parameters of black pepper powder before and after RF treatment

Sl. No.	Quality Parameter	Before RF Treatment	After RF Treatment	SEm±	CD @1%	CV
1.	Moisture content, % (w.b.)	9.67 ± 0.02^a	8.45 ± 0.10^b	0.042	0.27	0.796
2.	Water activity, a_w	0.64 ± 0.01^a	0.424 ± 0.01^b	0.01	0.05	2.43
3.	Bulk density, g.ml^{-1}	0.521 ± 0.02^a	0.48 ± 0.15^a	0.01	0.07	3.61
4.	Tapped density, g.ml^{-1}	0.64 ± 0.02^a	0.59 ± 0.02^a	0.01	0.09	3.90
5.	Colour (L^*)	49.84 ± 0.63^a	49.58 ± 0.14^a	0.06	0.14	0.07
	Colour (a^*)	3.1 ± 0.10^a	3.3 ± 0.1^a	0.05	0.14	0.06
	Colour (b^*)	12.4 ± 0.20^a	12.1 ± 0.1^a	0.14	0.14	1.80
6.	Piperine content, mg.g^{-1}	50.07 ± 1.60^a	49.38 ± 2.93^a	0.142	0.926	0.492
7.	Total phenolic content, mg GAE.g^{-1}	2.7 ± 0.11^a	2.9 ± 0.20^a	0.05	0.37	3.63
8.	DPPH radical scavenging activity	23.48 ± 0.51^a	23.55 ± 0.06^a	0.21	0.26	1.56

Note: Numbers within a row with same alphabet in superscript are not significantly different from each other ($p > 0.01$)
 L^* - Lightness; a^* - Redness; b^* - Yellowness

Table 2. Percentage of flavour components in black pepper essential oil

Sl. No.	Retention time, min	Compound	Untreated sample area, %	RF-treated sample area, %
1.	4.07	alpha-thujene	0.97±0.05	0.88±0.05
2.	4.21	alpha-pinene	4.84±0.26	4.37±0.28
3.	4.44	Camphene	0.12 ±0.01	0.11±0.01
4.	4.84	Sabinene	8.55±0.56	7.56±0.62
5.	4.94	beta-pinene	6.76±0.42	5.99±0.43
6.	5.14	beta-myrcene	1.63±0.11	1.44±0.12
7.	5.47	alpha-phellandrene	4.10±0.18	3.78±0.20
8.	5.66	3-carene	23.08±1.12	21.16±1.21
9.	5.75	2-carene	0.23±0.02	0.23±0.02
10.	5.81	o-cymene	0.99±0.02	0.95±0.02
11.	6.04	Limonene	18.17±1.33	15.87±1.39
12.	6.47	alpha-ocimene	0.04±0.01	0.04±0.01
13.	6.71	gamma terpinene	0.30±0.01	0.31±0.01
14.	6.89	alpha-terpinolene	0.06±0.01	0.07±0.00
15.	7.47	beta-bisabolene	1.00±0.01	1.01±0.00
16.	7.66	Linalool	0.36±0.03	0.42±0.03
17.	9.88	terpinen-4-ol	0.20±0.03	0.25±0.02
18.	15.24	alpha-terpinene	1.90±0.38	2.49±0.34
19.	15.66	alpha-cubebene	0.09±0.01	0.10±0.01
20.	16.5	Copaene	1.29±0.08	1.42±0.09
21.	16.9	beta-elemene	0.72±0.10	0.89±0.11
22.	17.87	Caryophyllene	22.17±2.99	27.50±3.28
23.	18.4	alpha-bulnesene	0.18±0.01	0.20±0.02
24.	18.8	alpha-caryophyllene	1.12±0.18	1.43±0.19
25.	19.61	β-Cubebene	0.09±0.01	0.11±0.02
26.	19.77	Alloaromadendrene	0.48±0.07	0.60±0.07
27.	20.87	delta-cadinene	0.38±0.07	0.50±0.07
28.	24.27	delta cadinol	0.21±0.06	0.30±0.06

found to be 23.48 ± 0.06 and 23.55 ± 0.01 , respectively. It was observed that the radical scavenging activity in the RF treated sample was slightly higher. An increase in radical scavenging activity might be due to the solubility of active compounds increase after thermal treatment that decomposed the cell wall and released the antioxidants. This might also be because of the ionization of active molecules during RF heating. Similar results were also reported by Shobana and Naidu (2000) and Tomaino *et al.* (2005) for thermal treatment of spices.

Essential Oil Composition

The composition of black pepper essential oil before and after RF treatment are presented in Table 2. There were 28 number of compounds detected in GC-MS analysis; and among these six hydrocarbon compounds *viz.*, alpha-pinene, Sabinene, beta-pinene, 3-carene, limonene and caryophyllene constituted 83% of the total volatiles. It is also seen that RF treatment resulted in relatively lesser thermal degradation of majority of

the compounds, except the caryophyllene. The increase in caryophyllene content might be due to the breakdown of flavonoides in living cells as glycosides by enzymatic reaction during RF treatment to form their aglycone and sugar resulting in production of caryophyllene. Similar results were reported by Skąpska *et al.* (2003) for essential oil in black pepper treated at high pressure (100 MPa) and temperature (140°C).

It was also reported that the use of thermal treatment as heat shock at 70°C for 15 min reduced the bacterial and fungal counts by about 3 to 4 log cycle, besides decreasing the total aerobic thermo-philic and the other pathogenic microbes in different spices (Farak *et al.*, 1996). The following are some research studies conducted on RF heating for inactivation of food borne pathogens in the recent years (Byrne *et al.*, 2010 for meat products, Uemura *et al.*, 2011 for soya milk, Kim *et al.*, 2012 for black and red pepper, Kim *et al.*, 2013 for peanut butter Schlisselberg *et al.*, 2013 for ground beef).

CONCLUSIONS

The results of the present study indicated that RF heating of black pepper powder up to 70 °C and maintaining at same temperature for 15 min in hot air oven did not cause significant changes in the physical properties *viz.*, colour, bulk density and tapped density and bio-chemical composition *viz.*, piperine content (50.07 ± 1.60 mg.g⁻¹ and 49.38 ± 2.93 mg.g⁻¹), total phenolics (2.9 ± 0.20 and 2.7 ± 0.10 mg of GAE.g⁻¹) and radical scavenging activity (23.48 ± 0.06 and 23.55 ± 0.01) of black pepper powder. RF heating could be a promising alternative disinfection technology for black pepper and similar spices without affecting their physical and bio-chemical properties.

REFERENCES

- AOAC.** 2005. Association of Analytical Chemists. Official Methods of Analysis (18th Edn, Method 986.21), Gaithersburg, MD, USA, 45-48.
- Andrade K S; Ferreira S R.** 2013. Antioxidant activity of black pepper (*Piper nigrum* L.) oil obtained by supercritical CO₂. III Iberoamerican Conference on Supercritical Fluids Cartagena de Indias, Colombia, 1-5.
- Anon.** 2010. Centers for Disease Control and Prevention - A nationwide outbreak of Salmonella Montevideo infections associated with salami products made with contaminated imported black and red pepper - United States. Morbidity and Mortality Weekly Report, 59, 1647–1650.
- Birla S L; Wang S; Tang J; Tiwari G.** 2008. Characterization of radio frequency heating of fresh fruits influenced by dielectric properties. J. Food Eng., 89, 390–398.
- Byrne B; Lyng J G; Dunne G; Bolton D J.** 2010. Radio frequency heating of comminuted meats – considerations in relation to microbial challenge studies. Food Control, 21, 125–131.
- Casal C; Vinas I; Landl A; Picouet P; Torres R ; Usall J.** 2010. Application of radio frequency heating to control brown rot on peaches and nectarines. Postharvest Biol. Technol., 58, 218-224.
- Farag Zaied S E A; Aziz N H; Ali A M.** 1996. Comparing effects of washing, thermal treatments and gamma irradiation on quality of spices. Mol. Nutr. Food. Res., 40, 32–36.
- Farkas J.** 2006. Irradiation for better foods. Trends Food Sci. Technol., 17, 148–152.
- Gao M; Tang J; Wang Y; Powers J; Wang S.** 2010. Almond quality as influenced by radio frequency heat treatments for disinfestation. Postharvest Biol. Technol., 58 (3), 225–231.
- Gao M; Tang J; Villa-Rojas R; Wang Y; Wang S.** 2011. Pasteurization process development for controlling Salmonella in in-shell almonds using radio frequency energy. J. Food Eng., 104 (2), 299–306.
- Geveke David; Brunkhorst Christopher; Fan Xuotong.** 2007. Radio frequency electric fields processing of orange juice. Innovative Food Sci. Emerging Technol., 8, 549-554.
- Ha J W; Kim S Y; Ryu S R; Kang D H.** 2013. Inactivation of *Salmonella enterica* serovar Typhimurium and *Escherichia coli* O157:H7 in peanut butter cracker sandwiches by radio-frequency heating. Food Microbiol., 34, 145–150.
- He S D; Li J; He Q; Jian H; Zhang Y; Wang J; Sun H J.** 2018. Physicochemical and antioxidant properties of hard white winter wheat (*Triticum aestivum* L.) bran superfine powder produced by eccentric vibratory milling. Powder Technol., 325, 126–133.
- Jeong Seul-Gi; Dong-Hyun Kang.** 2014. Influence of moisture content on inactivation of *Escherichia coli* O157:H7 and *Salmonella enterica* serovar Typhimurium in powdered red and black pepper spices by radio-frequency heating. Int. J. Food Microbiol., 176, 15–22.
- Jojo Sona; Mahendran R.** 2013. Radio frequency heating and its application in food processing: A review. Int. J. Current Agric. Res., 1(9), 42-46.
- Kim Ha J W; Ryu S Y; Kang D H.** 2013. Inactivation of *Salmonella enterica* serovar Typhimurium and *Escherichia coli* O157:H7 in peanut butter cracker sandwiches by radio-frequency heating. Food Microbiol., 34, 145–150.
- Kim S Y; Sagong H G; Choi S H; Ryu S R; Kang D H.** 2012. Radio-frequency heating to inactivate *Salmonella* Typhimurium and *Escherichia coli* O157:H7 on black and red pepper spice. Int. J. Food Microbiol., 153, 171–175.
- Kimber M A; Kaur H; Wang L; Danyluk M D; Harris L J.** 2012. Survival of *Salmonella*, *Escherichia*

coli O157:H7, and *Listeria monocytogenes* on inoculated almonds and pistachios. *J. Food Prot.*, 75, 1394-1403.

Magulska Beata Ulewicz-; Marek Wesolowski. 2019. Total phenolic contents and antioxidant potential of herbs used for medical and culinary purposes. *Plant Foods Human Nutr.*, 74(1), 61-67.

Marra F; Zhang L; Lyng J G. 2009. Radio frequency treatment of foods: Review of recent advances. *J. Food Eng.*, 91, 497-508.

Meghwal Murlidhar; Goswami T K. 2012. Chemical composition, nutritional, medicinal and functional properties of black pepper: A review. *Open Access Sci. Rep.*, 1. doi:10.4172/scientificreports.172

Pereira R N; Vicente A A. 2010. Environmental impact of novel thermal and non-thermal technologies in food processing. *Food Res. Int.*, 43, 1936–1943.

Rico C W; Kim G R; Ahn J J; Kim H K; Furuta M; Kwon J H. 2010. The comparative effect of steaming and irradiation on the physicochemical and microbiological properties of dried red pepper (*Capsicum annum L.*). *Food Chem.*, 119, 1012–1016.

Schweiggert U; Carle R; Schieber A. 2007. Conventional and alternative processes for spice production—A review. *Trends Food Sci. Technol.*, 18, 260–268.

Shobana S; Naidu K A. 2000. Antioxidant activity of selected Indian spices. *Prostaglandins Leukotrienes, Essent. Fatty Acids*, 62 (2), 107-110.

Tiwari G; Wang S; Tang J; Birla S L. 2011. Analysis

of radio frequency (RF) power distribution in dry food materials. *J. Food Eng.*, 104, 548–556.

Tomaino A; Cimino F; Zimbalatti V; Venuti V; Sulfaro V; Pasquale D A; Saija A. 2005. Influence of heating on antioxidant activity and the chemical composition of some spice essential oils. *Food Chem.*, 89, 549-554.

Tran Thien Hien; Ha L K; Nguyen D C; Dao T P; Nhan L T H; Nguyen Dai Hai; Nguyen Trinh Duy; Vo Dai-Viet N; Tran Q T; Bach Long Giang. 2019. The study on extraction process and analysis of components in essential oils of black pepper (*Piper nigrum L.*) seeds harvested in Gia Lai Province, Vietnam. *Processes*, 7 (2), 1-15.

Uemura K; Takahashi C; Kobayashi I. 2010. Inactivation of *Bacillus subtilis* spores in soybean milk by radio-frequency flash heating. *J. Food Eng.*, 100, 622–626.

Waje C K; Kim H K; Kim K S; Todoriki S; Kwon J H. 2008. Physicochemical and microbiological qualities of steamed and irradiated ground black pepper (*Piper nigrum L.*). *J. Agric. Food Chem.*, 56(12), 4592-4596.

Wang S; Ikediala J N; Tang J D; Hansen E; Mitcham Mao; Swanson B. 2001. Radio frequency treatments to control codling moth in in-shell walnuts. *Postharvest Biol. Technol.*, 22 (1), 29–38.

Zarai z; Boujelbene E; Salem N B; Gargouri Y S. 2013. Antioxidant and antimicrobial activities of various solvent extracts, piperine and piperic acid from *Piper nigrum*. *LWT - Food Sci. Technol.*, 50, 634-641.