Available online freely at www.isisn.org

Bioscience Research

Print ISSN: 1811-9506 Online ISSN: 2218-3973

Journal by Innovative Scientific Information & Services Network

RESEARCH ARTICLE BIOSCIENCE RESEARCH, 2020 17(3):2178-2186. **OPEN ACCESS**

Feasibility of radio frequency as Dry Blanching to Physicochemical characteristics of Paddy Straw Mushroom (*Volvariella* spp.)

Nguyen Phuoc Minh

Faculty of Food Science and Technology, Thu Dau Mot University, Binh Duong Province, **Vietnam**

***Correspondence:** nguyenphuocminh@tdmu.edu.vn **Received 04-08-2020, Revised: 18-09-2020, Accepted: 24-09-2020 e-Published: 30-09-2020**

Paddy straw mushroom (*Volvariella* spp.) was extensively cultivated and consumed in Vietnam. It was highly perishable after harvesting due to high respiration rate and enzymatic reaction, speciallypolyphenoloxidase. This enzyme was mostly responsible for pericarp browning appearance. The common traditional method to retard the discoloration in fruits and vegetables by enzymatic inactivation was the hot water blanching. Unfortunately, hot water blanching was not suitable for blanching straw mushroom to inactivate polyphenoloxidase because it would absorbed a lot of moisture and its structural appearance would become seriously broken under submersion. Dry blanching was very necessary to overcome this matter. Radio frequency heating was an innovative emerging alternative for food industry because of its excellent penetration depth, heat distribution and low energy consumption. This research evaluated the feasibility of radio frequency heating as dry-blanching in different values of electrode gaps (7.0÷15 cm) and blanching duration (3÷11 min) on polyphenoloxidase activity, texture firmness, vitamin C of mushroom. Results showed that radio frequency heating effectively inactivated polyphenoloxidase activity while maintaining the most texture firmness and vitamin C content. Shelf life of the treated samples extended for long stability on racks of supermarket. This research indicated that radio frequency heating as dry blanching should be widely implemented to keep its freshness during handling, distribution as well as preliminary processing before deep-processing into value-added products.

Keywords: Firmness, polyphenoloxidase, radio frequency blanching, shelf life, paddy straw mushroom, vitamin C

INTRODUCTION

Paddy straw mushroom had unique flavour, aroma, delicacy; high content of protein, vitamins and minerals (Biswas, 2017). The fruiting body started with tiny clusters of white hyphal aggregates called primordia following by several morphological stages in the fruiting body development process. Paddy straw mushroom was very delicate in nature and highly perishable due to thin and porous epidermal structure as well as the respiration rate causing to pericarp browning and aril decay leading to shorten post-harvest shelf life and degradation of commercial value (Warwick and Tsureda, 1997). It passed successive stages as button, egg, elongation and mature. Differentiation could be clearly noticed at the button stage. At maturity the buttons enlarged and umbrella like fruit bodies emerged after the rupture of the volva. Its commercial value went down at that time (Minh and Hang, 2019). Its shelf life was not over 3 days at ambient storage; therefore special care to retain freshness was very necessary (Lee, 1999).

The polyphenoloxidase was a copper-containing enzyme contributing to enzymatic browning of vegetables and fruits. Its activity can

be inhibited by chemical reagents, such as sulphites, ascorbic acid, and amino acids. However the residual chemical agents pose a threat to human health. Blanching was the most common and effective technique to control enzymatic browning and enzymatic inactivation in the food industry. Radio frequency heating was one of the most promising thermal techniques used electromagnetic energy at a frequency range of 3 kHz to 300 MHz and initiated volumetric heating due to frictional interaction between molecules (Jojo and Mahendran, 2013). The electromagnetic heating process was relatively quick and took place through the transmission of electromagnetic energy directly to the product. The heat was generated within the product without the need for heat transference (Datta and Davidson, 2000). Shorter wavelengths are associated with higher frequencies (Awuah et al. 2015). The penetration depth of dielectric heating decreased as frequency increased (Wang et al. 2003b). The long wavelengths of radio frequency are able to penetrate further into foodstuffs resulting in more even heating (Ammar et al. 2019). Radio frequency heating was more suitable for thick fruits and vegetables (Hong-Wei et al. 2017). The advantages of radio frequency heating included higher penetration depth and higher heating rate. Therefore, it could save processing time and improve food quality (Piyasena et al. 2003). It could be applicable to eggs, meats, nuts, legumes, seeds, grains, seafoods, fruits and vegetables to inactivate microorganism and enzyme, control pest, temper, disinfestation owing to quick heating, low cost, deep thermal penetration, and better quality retention cited by many literatures (Wang et al. 2001; Ikediala et al. 2002; Piyasena et al. 2003; Wang et al. 2003a; Birla et al. 2004; Zhang et al. 2004; Alholy et al. 2005; Brunton et al. 2005; Drake et al. 2005; Guo et al. 2006; Luechapattanaporn et al. 2006; Hansen et al. 2006; Schustergajzago et al. 2006; Lyng et al. 2007; Wang et al. 2007; Farag et al. 2008; Manzocco et al. 2008; Tiwari et al. 2008; Farag et al. 2009; Fortune et al. 2010; Gao et al. 2010; Lopez and Baganis, 2010; Wang et al. 2010; Zhao et al. 2010; Farag et al. 2011; Fiore et al. 2013; Sisquella et al. 2013; Hou et al. 2014; Sisquella et al. 2014; Uyar et al. 2014; Yang et al. 2014; Hou et al. 2015; Liu et al. 2015; Llave et al. 2015; Uyar et al. 2015; Ferrari-John et al. 2016; Hou et al. 2016; Huang et al. 2016; Jiao et al. 2016; Nagaraj et al. 2016; Stefanoiu et al. 2016; Erdogdu et al. 2017; Geveke et al. 2017; Guo et al. 2017; Li et al. 2017; Palazoğlu and Miran, 2017; Ranjan et al. 2017; Xu et al. 2017a; Xu et al. 2017b; Uemuraet al. 2017; Zhang et al. 2017; Zhao et al. 2017; Zheng et al. 2017; Zhu et al. 2017; Kou et al. 2018; Lyu et al. 2018; Chaofan et al. 2019).

The conventional hot water blanching treatment effectively prevented the enzymatic browning reaction in fruits and vegetables. Unfortunately, this thermal treatment was not always suitable for blanching straw mushroom for polyphenol oxidase inactivation because it was easily absorbed water and damaged to structural property. Heating without water was essential to resolve this problem. Objective of our study evaluated the possibility of radio frequency heating as dry-blanching on various parameters of electrode gaps and blanching duration on polyphenol oxidase activity, texture firmness, vitamin C of paddy straw mushroom.

MATERIALS AND METHODS

Material

Paddy straw mushroom bulbs were harvested in SocTrang province, Vietnam. They were cultivated following VietGAP standard to ensure food safety. After collecting, they were thoroughly rolled out to separate foreign matters. Chemical reagents were all analytical grade.

Researching method

Radio frequency blanching was conducted by a pilot scale free running oscillator radio frequency system. The system composed one generator and applicators with two rectangular electrodes arranged side by side. Different values of electrode gaps (7.0÷15 cm) and blanching duration (3÷11 min) on polyphenoloxidase activity, texture firmness, vitamin C of mushroom were investigated.

Physicochemical analysis

Firmness (N) was evaluated by texture analyzer. Polyphenol oxidase activity (U/ml/min) was determined by spectrophotometer according to the method of Zhang et al. (2018). Vitamin C (mg/100g) was determined by using a 2,6-dichlorophenol indophenol visual titration method.

Statistical analysis

The experiments were run in triplicate with different groups of samples. The data were presented as mean±standard deviation. Statistical analysis was performed by the Stat graphics Centurion version XVI.

RESULTSAND DISCUSSION

Firmness

The main purpose of blanching was to inactivate quality-changing enzymes responsible for deterioration reactions that contributed to off-flavors, odors, undesirable color and texture, and breakdown of nutrients (Hong-Wei et al. 2017). Texture firmness was frequently used as a primary indicator to evaluate blanching process for acceptable product quality as consumer requirements (Nourian et al. 2003; Xiao et al. 2012). The softening of the final textural properties of the product was due to both turgor loss caused by cell membrane disruption and modifications in cell wall polymers, especially the pectic substances (Greve et al. 1994). In our research, the original firmness of paddy straw mushroom was 0.28 N. The statistical analysis revealed that both electrode gap and blanching duration had significant effect on the firmness retention of the treated paddy straw mushroom (table 1). Large temperature gradients generated within the samples during heating resulted in internal water vaporization, leading to textural damage of mushroom (Rodriguez-Lopez et al. 1999). Zhenna et al. (2018) examined the effects of radio frequency assisted blanching on polyphenol oxidase, weight loss, texture, color and microstructure of potato. Electrode gap had significant impact on firmness of the potato cuboids.

Polyphenoloxidase

Polyphenoloxidase was predominantly presented in the chloroplast of thylakoid membranes while phenolics were located in vacuoles (Spagna et al. 2005). Browning reaction occured naturally due to action of the enzyme polyphenol oxidase in the presence of oxygen on phenolic compounds and resulting in a brown compound called *o*-Quinones (Al-Amrani et al. 2020). *o*-Quinones polymerized nonenzymatically to produce heterogeneous deep dark polymers called melanin (Li et al. 2016). Polyphenoloxidase performed as a promoter for peroxidase activity because hydrogen peroxide which was a product of polyphenoloxidase reaction with phenolics was essential for peroxidase action. Peroxidase catalyzed oxidation of phenolics in the presence of hydrogen peroxide to form brown compounds (Tomas-Barberan and Espin, 2001). In our research, the original polyphenoloxidase activity of paddy straw mushroom was 24.39 U/ml/min. Our results revealed that electrode gap had no significant effect on the polyphenoloxidase inactivation while blanching duration had significant effect on the polyphenoloxidase inactivation of the treated paddy straw mushroom (table 2). Our findings were similar to others in different reports. Devece et al. (1999) explored the combining microwave heating at 85 °C for different times and then immediately immersed in a 92 °C water bath for 20 s. Results clearly showed that this blanching in 2 min completely inactivated polyphenol oxidase in mushroom. Zhenna et al. (2018) examined the effects of radio frequency assisted blanching on polyphenol oxidase, weight loss, texture, color and microstructure of potato. They showed that pure mushroom polyphenol oxidase was almost completely inactivated at 80 °C by radio frequency heating. The relative activity of potato polyphenol oxidase reduced to less than 10% with increasing temperature (25–85 °C). Polyphenol oxidase relative activity of mushroom decreased with increase in temperature from 50 to 70°C at all electrode gaps (Zhang et al. 2018).

Ascorbic acid

Ascorbic acid was water soluble prone for leaching from cells. It's thermally labile, pH-, metal- ion-, and light-sensitive, and degradable by ascorbic acid oxidase (Uddin et al. 2001; Cruz et al. 2006). Stability of ascorbic acid after blanching was a good indicator for the preservation of other nutrients (Lin et al. 1998; Marfil et al. 2008). In our research, the original ascorbic acid content of paddy straw mushroom was 12.58 mg/100g. Our study showed that electrode gap and blanching duration had significant effect on the ascorbic acid retention of the treated paddy straw mushroom (table 3).

Schustergajzago et al. (2006) explored the effect of radio frequency heat treatment on nutritional and colloid-chemical properties of different white mustard (*Sinapisalba* L.) varieties. Tiwari et al. (2008) studied water-assisted radio frequency heat treatment on the quality of persimmons. Radio frequency heat treatments provided the potential for disinfestation of persimmons with acceptable product quality. Sisquella et al. (2013) immersed stone fruit in water with radio frequency treatment to control brown rot. Radio frequency treatment at 20 °C for 9 min significantly reduced brown rot incidence in both peaches and nectarines. Zhenna et al. (2017) treated potato cuboids by radio frequency blanching.

Table 1: Firmness (N) of straw mushroom by radio frequency heating

Blanching duration (min)	Electrode gap (cm)				
	7.0	9.0	11.0	13.0	15.0
3	0.21±0.01^{a}	0.22±0.00^{a}	0.24±0.03^{a}	0.25±0.02^{a}	0.26±0.00^{a}
5	0.20±0.03^{a}	0.21±0.02^{a}	0.23±0.01^{a}	0.24±0.00^{a}	0.25±0.03^{a}
7	0.18±0.00^{a}	0.19±0.01^{a}	0.21±0.02^{a}	0.22±0.03^{a}	0.23±0.02^{a}
9	0.17±0.02^{a}	0.18±0.03^{a}	0.19±0.00^{a}	0.21±0.01^{a}	0.22±0.00^{a}
11	0.15±0.01^{a}	0.16±0.00^{a}	0.17±0.03^{a}	0.18±0.02^{a}	0.20±0.01^{a}

Note: the values were expressed as the mean of twenty two samples; the same characters (denoted above), the difference between them was not significant (α = 5%).

Table 2: polyphenol oxidase activity (U/ml/min) of straw mushroom by radio frequency heating

Blanching duration (min)	Electrode gap (cm)				
	7.0	9.0	11.0	13.0	15.0
3	10.27±0.02^{a}	10.89±0.03^{a}	11.12±0.01^{a}	11.53±0.03^{a}	11.79±0.00^{a}
5	6.82±0.03^{ab}	7.03±0.01^{ab}	7.76±0.00^{ab}	7.98±0.01^{ab}	8.23±0.03^{ab}
7	4.13±0.00^{b}	4.52±0.02^{b}	4.84±0.03^{b}	5.01±0.00^{b}	5.24±0.01^{b}
9	2.74±0.01^{bc}	2.91±0.00^{bc}	3.05±0.01^{bc}	3.38±0.02^{bc}	3.63±0.00^{bc}
11	0.81±0.00^{c}	1.17±0.03^{c}	1.49±0.00^{c}	1.82±0.03^{c}	1.99±0.02^{c}

Note: the values were expressed as the mean of twenty two samples; the same characters (denoted above), the difference between them was not significant (α = 5%).

Table 3:Ascorbic acid (mg/100g) of straw mushroom by radio frequency heating

Blanching duration (min)	Electrode gap (cm)				
	7.0	9.0	11.0	13.0	15.0
3	9.75±0.03^{cd}	9.97±0.01^{c}	10.12±0.02^{bc}	10.31±0.01^{ab}	10.52±0.02^{a}
5	9.34±0.00^{de}	9.56±0.02^{d}	9.83±0.01^{cd}	9.99±0.00^{c}	10.18±0.01^{b}
7	9.02±0.01^{ef}	9.13±0.00^{e}	9.29±0.02^{de}	9.41±0.03^{d}	9.63±0.00^{d}
9	8.79±0.02^{fg}	8.91±0.03^{f}	9.12±0.00^{e}	9.28±0.01^{de}	9.44±0.02^{d}
11	8.55±0.00^{g}	8.74±0.01^{fg}	8.94±0.02^{f}	9.12±0.00^{e}	9.25±0.03^{de}

Note: the values were expressed as the mean of twenty two samples; the same characters (denoted above), the difference between them was not significant (α = 5%)

The optimum radio frequency heating uniformity was obtained at an electrode gap of 120 mm. Xu et al. (2017a) showed that the texture, water distribution, and rheological properties of *N. sphaeroides* under radio frequency heating were significantly lower than that in high pressure steam pasteurization. Xu et al. (2017b) proved that the combined sterilization effect of ZnO nanoparticles with radio frequency treatments was superior to ZnO nanoparticles or radio frequency heating treatment alone and extended the shelf life of prepared carrots up to 60 days. The effect of radio frequency heating on the browning and firmness of *C. militaris* was evaluated and compared with those sterilized by conventional high-pressure steam. *C. militaris* was pasteurized for 10, 20, and 30 min by radio-frequency at an electrode gap of 20 mm. Radio frequency heating observed good heating uniformity, uniform temperature distribution, unnoticeable browning difference, insignificant differences in hardness and chewiness compared with unpasteurized ones, while those sterilized by high-pressure steam presented undesired and unacceptable browning (Liang et al. 2018). Chuting et al. (2019a) proved that under radio frequency heating for 3.0–7.0 min at different electrode gaps 8.0–8.6 cm, peroxidase activity of carrot cubes was degraded by 90–95%, while retaining textural firmness, color and ascorbic acid content of carrots cubes much better than conventional blanching without generating of waste water.Chuting et al. (2019b) studied hot air-assisted radio frequency simultaneously dry-blanching and pre-drying of carrot cubes. It was better in vitamin C and firmness retention of carrot cubes. Kannan et al. (2019) investigated the effect of thickness (3, 6 and 10 mm) on quality of tomato

slices that were treated with a radio frequency radiation. The higher lycopene and total carotenoids content of 11.371±0.76 mg and 16±0.82 mg were observed for 3 mm thickness, 180 mm electrode height and 85°C temperature. Xueying et al. (2020) explored the optimum conditions of radio frequency blanching of apple slice. They concluded that electrode gap was of 120 mm was optimal for heating rate. Hardness retention in apple slice by radio frequency was higher than hot water blanching. It required 111 s and 270 s to reach the target temperature (85 °C) in radio frequency and hot water blanching respectively.

CONCLUSION

The shelf life of straw mushroom was limited due to the enzymatic browning during storage. Inactivation of polyphenoloxidase that caused browning through thermal blanching was essential to avoid enzymatic browning. During radio frequency heating, heat was generated within the product due to molecular friction resulting from oscillating molecules and ions caused by the applied alternating electric field. Frequency level, temperature, viscosity, moisture content and chemical composition affected to the dielectric properties and the heating efficiency. The great advantage of radio frequency as dry blanching that it could save water consumption as well as avoiding waste water discharge. Therefore it could be considered as low-cost environmentally friendly solution for enzyme inactivation, textural and nutritional retention..

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

ACKNOWLEGEMENT

We acknowledge the financial support for the publication provided by Thu Dau Mot University, Vietnam.

AUTHOR CONTRIBUTIONS

Nguyen Phuoc Minh arranged the experiments and also wrote the manuscript.

REFERENCES

Al-Amrani M., Al-Alawi A., Al-Marhobi I. (2020). Assessment of enzymatic browning and evaluation of antibrowning methods on dates.*Int J Food Sci.* 2020: 8380461.

Alholy M., Wang Y., Tang J., Rasco B. (2005). Dielectric properties of salmon (*Oncorhynchusketa*) and sturgeon (*Acipensertransmontanus*) caviar at radio frequency (RF) and microwave (MW) pasteurization frequencies.*J Food Eng* 70: 564–570.

Ammar A., Salah N. A., Al-Hilphy A. R. S., Naoufal L., Dennis G. W., Salam A. I. (2019). Critical review of radio-frequency (RF) heating applications in food processing.*Food Quality and Safety* 20: 1–11.

Awuah G. B., Ramaswamy H. S., Tang J. (2015). Radio-frequency heating in food processing principles and applications. Florida: CRC Press. p. 404.

Birla S. L., Wang S., Tang J., Hallman G. (2004) Improving heating uniformity of fresh fruit in radio frequency treatments for pest control. *Postharvest BiolTechnol* 33: 205–217.

Biswas M. K. (2017). Cultivation of paddy straw mushrooms (*Volvariellavolvacea*) in the lateritic zone of West Bengal-a healthy food for rural people.*International Journal of Economic Plants* 1: 043-047.

Brunton N. P., Lyng J. G., Li W., Cronin D. A., Morgan D., Mckenna B. (2005) Effect of radio frequency (RF) heating on the texture, colour and sensory properties of a comminuted pork meat product. *Food Res Int* 38: 337–344.

Chaofan G., Arun S. M., Min Z. (2019). New development in radio frequency heating for fresh food processing: A review. *Food Engineering Reviews* 11: 29–43.

Chuting G., Yanyun Z., Hangjin Z., Jin Y., Yubin M., Shunshan J. (2019a). Investigation of radio frequency heating as a dry-blanching method for carrot cubes. *Journal of Food Engineering*245: 53-56.

Chuting G., Hangjin Z., Jin Y., Yubin M., Shunshan J. (2019b). Investigation of hot air-assisted radio frequency heating as a

simultaneous dry-blanching and pre-drying method for carrot cubes.*Innovative Food Science and Emerging Technologies*56: 102181.

Cruz R. M. S., Vieira M. C., Silva C. L. M. (2006). Effect of heat and thermosonication treatments on peroxidase inactivation kinetics in watercress (*Nasturtium officinale*).*J Food Eng* 72: 8-15.

Datta A. K. and Davidson P. M. (2000).Microwave and radio frequency processing. *Journal of Food Science* 65: 32–41.

Devece C., Rodriguez-Lopez J. N., Fenoll L. G., Tudela J., Catala J. M., ReyesE. (1999). Enzyme inactivation analysis for industrial blanching applications: comparison of microwave, conventional, and combination heat treatments on mushroom polyphenoloxidase activity. *J Agric Food Chem* 47: 4506-4511.

Drake S. R., Heidt M. L., Hansen J. D., Watkins M. A., Tang J., Wang S. (2005) Evaluation of radio frequency-hot water treatments for postharvest control of codling moth in 'Bing' sweet cherries. *Horttechnology*15: 613–616.

Erdogdu F., Altin O., Marra F., Bedane T. F. (2017) A computational study to design process conditions in industrial radio-frequency tempering/thawing process. *J Food Eng*213: 99–112.

Farag K. W., Lyng J. G., Morgan D. J., Cronin D. A. (2008) A comparison of conventional and radio frequency tempering of beef meats: effects on product temperature distribution. *Meat Sci* 80: 488–495.

Farag K. W., Duggan E., Morgan D. J., Cronin D. A., Lyng J. G. (2009) A comparison of conventional and radio frequency defrosting of lean beef meats: effects on water binding characteristics. *Meat Sci* 83: 278–284.

Farag K. W., Lyng J. G., Morgan D. J., Cronin D. A. (2011) A comparison of conventional and radio frequency tempering of beef meats: effects on product temperature distribution. *Food Bioprocess Tech* 4: 1128–1136.

Ferrari-John R. S., Katrib J., Palade P., Batchelor A. R., Dodds C., Kingman S. W. (2016) A tool for predicting heating uniformity in industrial radio frequency processing. *Food Bioprocess Tech* 9: 1865–1873.

Fiore A., Di Monaco R., Cavella S., Visconti A., Karneili O., Bernhardt S., Fogliano V. (2013) Chemical profile and sensory properties of different foods cooked by a new radiofrequency oven. *Food Chem* 139: 515–520.

Fortune J. A., Wu B., Klibanov A. M. (2010) Radio frequency radiation causes no nonthermal damage in enzymes and living cells. *BiotechnolProg* 26: 1772–1776.

Gao M., Tang J., Wang Y., Powers J., Wang S. (2010) Almond quality as influenced by radio frequency heat treatments for disinfestation. *Postharvest BiolTechnol* 58: 225–231.

Geveke DJ, Bigley ABW, Brunkhorst CD (2017) Pasteurization of shell eggs using radio frequency heating. J Food Eng 193:53–57.

Greve L. C., Shackel K. A., Ahmadi H., McArdle R. N., Gohlke J. R., Labavitch J. M. (1994). Impact of heating on carrot firmness: contribution of cellular turgor. *J Agric Food Chem* 42: 2896-2899.

Guo Q., Piyasena P., Mittal G. S., Si W., Gong J. (2006). Efficacy of radio frequency cooking in the reduction of Escherichia coli and shelf stability of ground beef.*Food Microbiol* 23: 112–118.

Guo C. F., Zhang Z. N., Chen J. J., Fu H. F., Subbiah J., Chen X. W., Wang Y. Y. (2017) Effects of radio frequency heating treatment on structure changes of soy protein isolate for protein modification. *Food Bioprocess Tech* 10: 1574–1583.

Hansen J. D., Drake S. R., Watkins M. A., Heidt M. L., Anderson P. A., Tang J. (2006) Radio frequency pulse application for heating uniformity in postharvest codling moth (*Lepidoptera: Tortricidae*) control of fresh apples (*Malusdomestica*Borkh.). *J Food Qual* 29: 492–504.

Hong-Wei X., Zhongli P., Li-Zhen D., El-Mashad H. M., Xu-Hai Y., Arun S. M., Zhen-Jiang G., Qian Z. (2017). Recent developments and trends in thermal blanching – A comprehensive review.*Information Processing in Agriculture* 4: 101-127.

Hou L., Ling B., Wang S. (2014). Development of thermal treatment protocol for disinfesting chestnuts using radio frequency energy.*Postharvest BiolTechnol* 98: 65–71.

Hou L., Hou J., Li Z., Johnson J. A., Wang S. (2015). Validation of radio frequency treatments as alternative non-chemical methods for disinfesting chestnuts.*J Stored Prod Res* 63: 75–79.

Hou L., Johnson J. A., Wang S. (2016) Radio frequency heating for postharvest control of pests in agricultural products: a review. *Postharvest BiolTechnol* 113: 106–118.

Huang Z., Marra F., Subbiah J., Wang S. (2016) Computer simulation for improving radio frequency (RF) heating uniformity of food products: a review. *Crit Rev Food SciNutr* 58: 1–25.

Ikediala J. N., Hansen J. D., Tang J., Drake S. R., Wang S. (2002) Development of a saline water immersion technique with RF energy as a postharvest treatment against codling moth in cherries. *Postharvest BiolTechnol* 24: 209–221.

Jiao S., Zhong Y., Deng Y. (2016). Hot air-assisted radio frequency heating effects on wheat and corn seeds: quality change and fungi inhibition. *J Stored Prod Res* 69: 265–271.

Jojo S. and Mahendran R. (2013). Radio frequency heating and its application in food processing: A review. *International Journal of Current Agricultural Research* 1: 042-046.

Kannan R., Sunil C. K., Chidanand D. V. (2019). Effect of thickness on quality of tomato slices subjected to radio frequency assisted blanching. *International Journal of Chemical Studies* 7: 4139-4146.

Kou X., Li R., Hou L., Zhang L., Wang S. (2018) Identifying possible non-thermal effects of radio frequency energy on inactivating food microorganisms. *Int J Food Microbiol* 269: 89–97.

Lee J. S. (1999). Effects of modified atmosphere packaging on the quality of chitosan and $CaCl_2$ coated mushroom (*Agaricusbisporus*). *Korean Journal of Food Science and Technology* 31: 1308–1314.

Liang M., Min Z., Shuyong Z. (2018). Effect of radio-frequency heating on microbial load, flavor, color, and texture profiles of *Cordycepsmilitaris. Journal of the Science of Food and Agriculture* 99: 136-142.

Li H. J., Li J. X., Zhao Z. (2016). Characterization of melanin extracted from apricot (*Armeniacasibirica*) and its effect on hydrazine-induced rat hepatic injury. *ScienceAsia*. 42: 382–391.

Lin T. M., Durance T. D., Scaman C. H. (1998). Characterization of vacuum microwave, air and freeze dried carrot slices. *Food Res Int* 31: 111-117.

Li R., Kou X., Cheng T., Zheng A., Wang S. (2017). Verification of radio frequency pasteurization process for in-shell almonds.*J Food Eng* 192: 103–110.

Liu Q., Zhang M., Xu B., Fang Z., Zheng D. (2015) Effect of radio frequency heating on the sterilization and product quality of vacuum packaged Caixin. *Food Bioprod Process* 95: 47–54.

Llave Y., Liu S., Fukuoka M., Sakai N. (2015) Computer simulation of radiofrequency defrosting of frozen foods.*J Food Eng*152: 32–42.

Lopez A. and Baganis N. A. (2010) Effect of radio-frequency energy at 60 MHz on food enzyme activity. J Food Sci 36:911–914.

Luechapattanaporn K., Wang Y., Wang J., Tang J., Hallberg L. M., Dunne C. P. (2006). Sterilization of scrambled eggs in military polymeric trays by radio frequency energy.*J Food Sci* 70: 288–294.

Lyng J. G., Cronin D. A., Brunton N. P., Li W., Gu X. (2007) An examination of factors affecting radio frequency heating of an encased meat emulsion. *Meat Sci* 75: 470–479.

Lyu X., Peng X., Wang S., Yang B., Wang X., Yang H., Xiao Y., Baloch A. B., Xia X. (2018). Quality and consumer acceptance of radio frequency and traditional heat pasteurised kiwi puree during storage.*International Journal of Food Science and Technology* 53: 209–218.

Manzocco L., Anese M., Nicoli M. C. (2008).Radiofrequency inactivation of oxidative food enzymes in model systems and apple derivatives.*Food Res Int* 41: 1044–1049.

Marfil P. H. M., Santos E. M., Telis V. R. N. (2008). Ascorbic acid degradation kinetics in tomatoes at different drying conditions.*LWT – Food SciTechnol* 41: 1642-1647.

Minh N. P. and Hang L. P. (2019). Several factors affecting to shelf-life of paddy straw mushroom (*Volvariella* spp.) in preservation.*Plant Archives* 19: 444-448.

Nagaraj G., Purohit A., Harrison M. A., Singh R. K., Hung Y., Mohan A. (2016) Radiofrequency pasteurization of inoculated ground beef homogenate.*Food Control* 59: 59–67.

Nourian F., Ramaswamy H. S., Kushalappa A. C. (2003). Kinetics of quality change associated with potatoes stored at different temperatures. *LWT-Food SciTechnol* 36: 49-65.

Palazoğlu T. K. and Miran W. (2017) Experimental comparison of microwave and radio frequency tempering of frozen block of shrimp.*Innov Food SciEmerg* 41: 292–300.

Piyasena P., Dussault C., Koutchma T., Ramaswamy H. S., Awuah G. B. (2003).

Radio frequency heating of foods: principles, applications and related properties—a review. *Crit Rev Food SciNutr* 43: 587–606.

Ranjan S., Dasgupta N., Walia N., Chand C. T., Ramalingam C. (2017). Microwave blanching: an emerging trend in food engineering and its effects on *Capsicum annuum* L. *J Food Process Eng* 40: 12411.

Rodriguez-Lopez J. N., Fenoll L. G., Tudela J., Devece C., Sanchez-Hernandez D., Reyes E. (1999). Thermal inactivation of muchroompolyphenoloxidase employing 2450 MHz microwave radiation.*J Agri Food Chem* 47: 3029-3035.

Schustergajzago I., Kiszter A. K., Tothmarkus M., Barath A., Markusbednarik Z., Czukor B. (2006). The effect of radio frequency heat treatment on nutritional and colloid-chemical properties of different white mustard (*Sinapisalba* L.) varieties. *Innov Food SciEmerg* 7: 74–79.

Sisquella M., Casals C., Picouet P., Vinas I., Torres R., Usall J. (2013) Immersion of fruit in water to improve radio frequency treatment to control brown rot in stone fruit. *Postharvest BiolTechnol* 80: 31–36.

Sisquella M., Vinas I., Picouet P., Torres R., Usall J. (2014). Effect of host and Monilinia spp. variables on the efficacy of radio frequency treatment on peaches.*Postharvest BiolTechnol* 87: 6–12.

Spagna G., Barbagallo R., Chisari M., Branca F. (2005). Characterization of a tomato polyphenol oxidase and its role in browning and lycopene content.*Journal of Agricultural and Food Chemistry* 53: 2032- 2038.

Stefanoiu G. A., Tanase E. E., Mitelut A. C., Popa M. E. (2016). Unconventional treatments of food: microwave vs. radiofrequency. *AgricAgricSciProcedia* 10: 503–510.

Tiwari G., Wang S., Birla S. L., Tang J. (2008). Effect of water-assisted radio frequency heat treatment on the quality of 'Fuyu' persimmons.*BiosystEng* 100: 227–234.

Tomas-Barberan F. A. and Espin J. C. Phenolic compounds and related enzymes as determinants of quality in fruits and vegetables. *Journal of the Science of Food and Agriculture*. 81: 853–876.

Uddin M. S., Hawlader M. N. A., Zhou L. (2001). Kinetics of ascorbic acid degradation in dried kiwifruits during storage.*Drying Technol* 19: 437-446.

Uemura K., Kanafusa S., Takahashi C., Kobayashi I. (2017).Development of a radio frequency heating system for sterilization of vacuum-packed fish in water.*BiosciBiotechnolBiochem* 81: 762–767.

Uyar R., Bedane T. F., Erdogdu F., Palazoglu T. K., Farag K. W., Marra F. (2015) Radio-frequency thawing of food products—a computational study. *J Food Eng* 146: 163–171.

Uyar R., Erdogdu F., Marra F. (2014). Effect of load volume on power absorption and temperature evolution during radio-frequency heating of meat cubes: a computational study. *Food Bioprod Process* 92: 243–251.

Xiao H. W., Yao X. D., Lin H., Yang W. X., Meng J. S., Gao Z. J. (2012). Effect of SSB (superheated steam blanching) time and drying temperature on hot air impingement drying kinetics and quality attributes of yam slices. *J Food Process Eng* 35: 370-390.

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

Wang S., Tang J., Johnson J. A., Mitcham E., Hansen J. D., Hallman G., Drake S. R., Wang Y. (2003a). Dielectric properties of fruits and insect pests as related to radio frequency and microwave treatments. *BiosystEng* 85: 201–212.

Wang Y., Wig T. D., Tang J., Hallberg L. M. (2003b). Dielectric properties of foods relevant to RF and microwave pasteurization and sterilization.*J Food Eng* 57: 257-268.

Wang S., Monzon M., Johnson J. A., Mitcham E. J., Tang J. (2007). Industrial-scale radio frequency treatments for insect control in walnuts: I: heating uniformity and energy efficiency. *Postharvest BiolTechnol* 45: 240–246.

Wang S., Tiwari G., Jiao S., Johnson J. A., Tang J. (2010). Developing postharvest disinfestation treatments for legumes using radio frequency energy.*BiosystEng* 105: 341–349.

Warwick M. G. and Tsureda A. (1997).The interaction of the soft rot bacterium *Pseudomonas gladroli*.Agaricicoa with Japanese cultivated mushrooms. *Canadian Journal of Microbiology* 43: 639–648.

Xu J., Zhang M., Adhikari B. (2017a). Comparative study on the effect of radio frequency and high-pressure pasteurization on the texture, water distribution, and rheological properties of

Nostocsphaeroides.*J ApplPhycol* 30: 1041–1048.

Xu J., Zhang M., Bhandari B., Kachele R. (2017b). ZnO nanoparticles combined radio frequency heating: a novel method to control microorganism and improve product quality of prepared carrots. *Innov Food SciEmergTechnol* 44: 46–53.

Yang J., Tang J. M., Wang S. J., Koral T. (2014). Influence of dielectric properties on the heating rate in free-running oscillator radio frequency systems. *J Food Eng* 120: 197–203.

Zhang L., Lyng J. G., Brunton N. P. (2004). Effect of radio frequency cooking on the texture, colour and sensory properties of a large diameter comminuted meat product. *Meat Sci* 68: 257–268.

Zhang Z., Guo C., Gao T., Fu H., Chen Q., Wang Y. (2017). Pilot-scale radio frequency blanching of potato cuboids: heating uniformity. *Journal of the Science of Food and Agriculture* 98: 312–320.

Zhang Z., Wang J., Zhang X., Shi Q., Xin L., Fu H. (2018). Effects of radio frequency assisted blanching on polyphenol oxidase, weight loss, texture, color and microstructure of potato. *Food Chemistry* 248: 173-118.

Zhao Y., Flugstad B., Kolbe E., Park J. W., Wells J. H. (2010). Using capacitive (radio frequency) dielectric heating in food processing and preservation—a review. *J Food Process Eng*23: 25–55.

Zhao Y., Zhao W., Yang R., Singh S. J., Kong F. (2017). Radio frequency heating to inactivate microorganisms in broccoli powder.*Food Quality and Safety* 1: 93–100.

Zheng A., Zhang L., Wang S. (2017). Verification of radio frequency pasteurization treatment for controlling Aspergillusparasiticus on corn grains.*Int J Food Microbiol* 249: 27–34.

Zhenna Z., Chaofan G., Tong G., Hongfei F., Qin C., Yunyang W. (2017). Pilot-scale radiofrequency blanching of potato cuboids: heating uniformity. *Journal of the Science of Food and Agriculture* 98: 312-320.

Zhenna Z., Juan W., Xueying Z., Qingli S., Le X., Hongfei F., Yunyang W. (2018). Effects of radio frequency assisted blanching on polyphenol oxidase, weight loss, texture, color and microstructure of potato. *Food Chemistry* 248: 173–182.

Zhu H., Li D., Li S., Wang S. (2017). A novel method to improve heating uniformity in mid-high moisture potato starch with radio frequency assisted treatment. *J Food Eng*206: 23–36.