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Effects of combined radio frequency with hot water blanching on enzyme inactivation, color and texture of sweet potato

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ABSTRACT

Sweet potato is an important food crop with rich nutritional value, and also a commonly used feed and industrial raw material. However, the quality of sweet potatoes may decline during storage and thermal processes because of enzymatic reaction induced by peroxidase (POD). Radio frequency (RF) blanching was thus proposed to reduce POD activities. Effects of electrode gaps and sample thicknesses on the RF heating rate and uniformity in sweet potato were studied. Influences of hot water blanching and combination of RF heating with hot water blanching on enzyme inactivation and physiochemical properties of sweet potatoes were also analyzed. Results showed that the optimum RF heating uniformity was obtained at an electrode gap of 90 mm and a sample thickness of 60 mm. Combined RF with hot water blanching effectively inactivated POD in sweet potatoes. Compared to hot water blanching, combined RF with hot water blanching gave better sample color, texture values, and lower weight loss when achieving the same level of enzyme inactivation (< 10%). Therefore, combined RF with hot water blanching is recommended as an effective, uniform and high-quality blanching technology for sweet potatoes.

1. Introduction

Sweet potato (*Ipomoea batatas* [L.] Lam) is a major root crop and constitutes an integral part in the human diet (Shekhar, Mishra, Buragohain, Chakraborty, & Chakraborty, 2015). Sweet potatoes are popular among consumers due to their remarkably high amounts of carbohydrates, protein, vitamin C, and low-fat content (Lagnika et al., 2018). The global sweet potato production was 91.95 million tons in 2018 (FAOSTAT, 2020). However, it has been estimated that the annual maximum losses of sweet potatoes can reach up to 65% owing to its high moisture, fragility, and pest-attractive nature (Vithu, Dash, & Rayaguru, 2019).

Various post-harvest processing technologies have been developed for maintaining the quality of fruits and vegetables, such as frying, drying, and canning (Lagnika et al., 2018). However, biochemical changes induced by quality-related enzymes, such as polyphenol oxidase (PPO) and peroxidase (POD), in harvested vegetables and fruits would result in undesired quality degradation, including color and texture changes, off-flavors, and loss of nutrients (Terefe, Buckow, & Versteeg, 2014). Therefore, an inactivation procedure called blanching to reduce quality-related enzyme activity is indispensable before processing of fruits and vegetables.

Conventional blanching methods mostly use hot water and steam. However, conventional blanching has some drawbacks, such as long treatment time, water pollution, and degradation of product quality (Gong, Zhang, Yue, Miao, & Jiao, 2019). Therefore, emerging thermal processing techniques have been explored as alternatives to conventional blanching, such as microwave (MW), infrared (IR), and ohmic (OH) heating (Bhat, Saini, & Sharma, 2017; Dibanda, Akdowa, Rani, Tongwa, & Mbofung, 2020; Guiamba, Svanberg, & Ahrne, 2015). Despite their short time and effective efficiency in enzyme inactivation, they still have some disadvantages, such as shallow wave penetration and non-uniform heating.

Radio frequency (RF) treatment is a dielectric heating using electromagnetic waves at a range of 10 to 300 MHz (Zhou & Wang, 2019) through molecular and ionic frictions. Unlike OH heating, RF heating does not require direct contact with the product. RF heating also has deeper wave penetration than IR or MW heating. RF heating has been applied in food industry for various purposes, such as disinfestation (Liu & Wang, 2019), pasteurization (Li, Kou, Cheng, Zheng, & Wang, 2017), stabilization (Ling, Lyng, & Wang, 2018), and drying (Zhou & Wang, 2019).

Recently, RF heating has been investigated as blanching methods for fresh vegetables and fruits. These studies have focused on the effects

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of RF blanching on the dielectric properties (Xu, Wang, & Wang, 2019; Zhang, Guo, et al., 2018), quality (Gong et al., 2019; Gong, Zhang, et al., 2019; Zhang, Shi, et al., 2020), and microstructure (Yao et al., 2020; Zhang et al., 2018; Zhang et al., 2020) of fruits and vegetables. However, these studies seldom improved RF heating uniformity, which is needed to be overcome before scaling up for practical industrial implementations. Since RF wave could quickly raise internal sample temperature to desired point, it is often applied in pre-heating period and then combined with conventional surface heating, such as hot water, to improve the RF heating uniformity (Zhou & Wang, 2019). Hence, the combined RF with hot water blanching would offer potential to improve heating uniformity, enzyme inactivation efficiency and final product quality.

The objectives of this study were: (1) to study the effect of electrode gaps and sample thicknesses on the heating rate and uniformity of sweet potatoes during RF blanching, (2) to explore the enzyme activity of sweet potatoes after hot water blanching and combination of RF heating with hot water blanching, and (3) to compare the color and texture of sweet potatoes between the two blanching methods.

2. Materials and methods

2.1. Material preparation

Sweet potatoes (*Ipomoea batatas* Qinshu No.5) with similar size were obtained from a local market in Yangling, Shaanxi, China. After checking carefully to discard blemished samples, they were stored in a refrigerator at 4 °C and used within two weeks. Before each experiment, samples were taken out and equilibrated in an incubator at 25 ± 0.5 °C for 10 h. Sweet potatoes were hand-peeled and cut into cylinders by a custom-designed metal mold. Samples used for RF heating uniformity evaluation were prepared with diameter 33.3 ± 0.3 mm and three thicknesses (55.2 ± 0.3, 60.1 ± 0.3, and 65.1 ± 0.2 mm). Samples used to compare single hot water blanching and combined RF with hot water blanching had a diameter of 33.3 ± 0.3 mm and a thickness of 60.1 ± 0.3 mm.

2.2. RF treatment

2.2.1. RF heating system

A 6 kW, 27.12 MHz pilot-scale free running oscillator RF system (SO6B, Strayfield International, Wokingham, UK) combined with a hot-air system supplied by a 6 kW electric heater was used for RF blanching treatments (Fig. 1). The parallel electrode gap could be adjusted between 90 and 190 mm to regulate the RF power. The main features of the RF system are described in Liu and Wang (2019).

2.2.2. Determining the effect of electrode gaps and sample thicknesses on heating rate

POD is one of the most heat-resistant enzymes in fruits and vegetables, and its 90% inactivation is usually considered as the endpoint of blanching treatment (Severini, Giuliani, Filippis, Derossi, & De Pilli, 2016). According to the study conducted by Wu et al. (2014), a temperature of 90 °C with 20 min blanching can inactivate 91.4% of POD for carrot slices. Thus, 90 °C was selected as the target temperature in the RF heating.

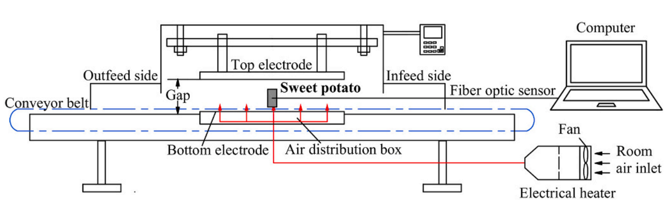

Fig. 1. Schematic view of the pilot-scale 6 kW, 27.12 MHz RF system (adapted from Liu & Wang, 2019).

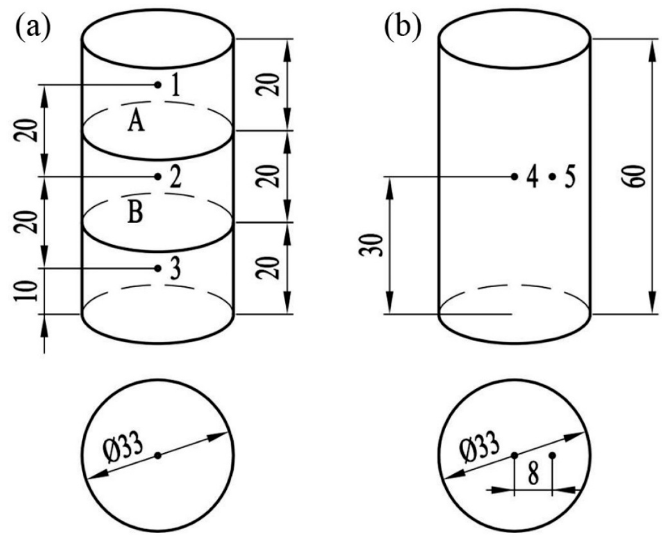

Fig. 2. Two layers (first, A; second, B) and five locations (1, 2, 3, 4, and 5) for measuring temperatures of samples (all dimensions are in mm) subjected to radio frequency heating (a) and hot water heating (b).

Three electrode gaps (90, 100, and 110 mm) and three sample thicknesses (55, 60, and 65 mm) were selected for RF heating according to our preliminary test. The cylinder-shape sample (33 mm diameter) was placed at the geometric center of a polypropylene rectangular container (240 mm length, 180 mm width, and 20 mm thickness) with its side and bottom walls perforated with 10-mm diameter holes. The container was placed at the center of the bottom electrode. During RF heating, the hot air system (60 °C and an air velocity of 1.0 m/s) was turned on to remove surface vapor rapidly according to Gong, Zhang, et al. (2019), and three fiber-optic temperature sensors (HQ-FTS-D120, Heqi Technologies Inc., Xian, China) connected to a data logger were used to record sample temperatures. The fiber-optic sensors were inserted at positions 1, 2, and 3 of the sweet potato cylinders (Fig. 2a). The average temperature of the three temperature measuring points over three replicates was used to develop the time-temperature histories. The RF system was turned off when the average sample temperature reached 90 °C according to the recorded time-temperature histories.

2.2.3. Determining the effect of electrode gaps and sample thicknesses on heating uniformity

After RF heating, the cylinder sample was taken out and the surface temperature distributions of first (A) and second (B) layers were mapped by an infrared camera (FLIR A300, FLIR Systems, Stockholm, Sweden) (Fig. 2a). More detailed information about the camera calibration and measurement procedure can be found in Zhou, Ramaswamy, Qu, Xu, and Wang (2019).

The heating uniformity index (λ) has been proposed by Wang, Yue, Tang, and Chen (2005) to estimate temperature distributions of samples in the RF treatment. This index has been successfully used for evaluating RF heating uniformity in many studies (Zhang, Guo, et al., 2018; Zhou et al., 2019). The heating uniformity index is defined as the ratio of the rise in standard deviation of sample temperatures to the rise in average sample temperatures over the treatment time and can be calculated by the following equation (Wang, Monzon, Johnson, Mitcham, & Tang, 2007):

$$\lambda = \frac{\Delta\sigma}{\Delta\mu} \tag{1}$$

Where $\Delta\mu$ is the rise in mean temperatures (°C) of sample and $\Delta\sigma$ is the rise in standard deviations (°C) of sample temperatures over RF heating time. The smaller value of λ represents the better RF heating uniformity.

2.3. Determining the effect of blanching methods on enzyme inactivation

2.3.1. Hot water blanching

Sweet potatoes were immersed into hot water (90 °C) using a thermostatically controlled water bath (SC-15, Ningbo Scientz Biotechnology Co., Ltd., Ningbo, China). The blanching times were determined as 5, 10, and 15 min according to preliminary tests. The temperatures of sweet potatoes subjected to hot water blanching (HWB) were measured at positions 4 and 5 (Fig. 2b). After HWB, sweet potato samples were taken out of hot water and immediately put into cold water (9.0 ± 0.5 °C) to prevent excessive heating until the temperature of samples dropped to 25 °C. After that, samples were taken out of cold water. The excess water on the surface of sweet potatoes was removed with filter paper. Prior to analysis, samples were individually packed in zip-lock polyethylene bags and stored in the refrigerator at 4 °C.

2.3.2. Combined radio frequency with hot water blanching

Combined RF with hot water blanching (RFB + HWB) had two stages of RF pre-heating and hot water holding. Samples were first heated by RF energy to 90 °C and then put in a hot water bath (90 °C) for three different holding times (2, 4, and 6 min) (Fig. 3). The total time interruption for transferring the sample from the RF cavity to the hot water bath was less than 20 s. After holding period, samples were immediately removed from hot water bath and cooled to 25 °C using cold water (9.0 ± 0.5 °C). The excess water on the sample surface was removed with filter paper, and then samples were stored in zip-lock polyethylene bags in the refrigerator at 4 °C for further quality analysis.

2.3.3. Enzyme extraction and activity assay

Sweet potato POD was extracted according to the method as described by Lilia, Hernando, Isabel, Giampiero, and Paola (2011) with some modifications. Briefly, 20.0 g samples of each batch and 100 mL of potassium phosphate buffer (0.1 M, pH 6.5, 4 °C) were mixed using a homogenizer (FSH-2A, Chengdong Xinrui Instrument Company, Jintan, China) at 13,000 rpm for 1 min. Subsequently, the homogenized solution was filtered through filter paper and centrifuged at 4000 rpm for 15 min. Then, the supernatant was collected as enzyme extract for determining the POD activity.

POD activity was determined according to the method reported by Morales-Blancas, Chandia, and Cisneros-Zevallos (2002) using a spectrophotometer (UV-2000, Unic Instrument Co., Ltd., Shanghai, China) at 470 nm with slight modifications. POD substrate solution was prepared by mixing 0.1 mL of 99% guaiacol, 0.1 mL of 30% hydrogen peroxide, and 99.8 mL of 0.1 M potassium phosphate buffer (pH 6.5). The absorbance of the reaction mixture composed of 0.1 mL of enzyme extract and 2.9 mL of substrate solution was measured every 30 s for a total of 3 min. The substrate solution served as the blank. One unit of enzyme activity was defined as the amount of enzyme required to raise the absorbance by 0.001 per min under these conditions. The relative enzyme activity (*REA*) can be calculated by the following equation:

$$REA = \frac{A}{A_0} \times 100\% \tag{2}$$

Where A and A_0 are the enzyme activities of blanched samples and fresh sweet potatoes, respectively.

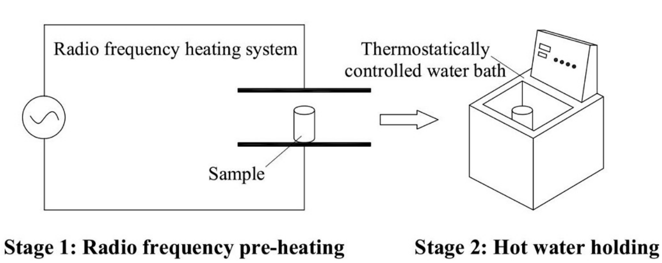

Fig. 3. Schematic view of the combination of RF heating with hot water blanching.

2.4. Quality evaluation

2.4.1. Weight loss and moisture content determination

The weight loss (*WL*, kg) is defined as the ratio of the lost weight to the initial weight (W_0, kg). The W_0 of sweet potatoes prior to blanching and the weight after blanching (W_1, kg) were recorded. The *WL* can be calculated as follows:

$$WL = [(W_0 - W_1)/W_0] \times 100\% \tag{3}$$

The moisture content of the sample was determined by the AOAC Official vacuum oven Method 925.40 (AOAC, 2005).

2.4.2. Color and texture measurement

The colors of fresh and blanched sweet potato samples were measured using a computer vision system. Detailed information about the color measurement system and procedures can be found in Hou, Ling, and Wang (2015). The color was expressed in the CIE systems where the values of L^*, a^*, and b^* presented darkness-lightness, greenness-redness, and blueness-yellowness, respectively. The total color difference (ΔE) can be calculated as follows:

$$\Delta E = \sqrt{(L_t^* - L_0^*)^2 + (a_t^* - a_0^*)^2 + (b_t^* - b_0^*)^2} \tag{4}$$

Where subscripts "0" and "t" refer to the color value of fresh and blanched samples, respectively. A larger ΔE stands for a larger color change from the fresh sweet potato.

Texture of sweet potato samples was determined by a texture analyzer (TA.XTC-18, Shanghai Baosheng Industrial Development Co., Ltd., Shanghai, China). Pre-test speed was 3 mm/s while both test speed and post-test speed were 1 mm/s. The distance between TA/2 probe and platform was set to 10 mm. Compression displacement was set to 5 mm, while holding-time was 5 s and trigger value was 5 g. The hardness, frangibility, and chewiness of the samples were measured and calculated.

2.5. Statistical analysis

The results are expressed as mean ± standard deviations over three replicates. Significant differences ($P < 0.05$) among means were determined by the analysis of variance and Tukey's significant difference test using the statistical software SPSS 20.0 version (SPSS Inc., Chicago, IL, USA).

3. Result and discussion

3.1. Effects of electrode gaps and sample thicknesses on heating rate of RF heating

Fig. 4 shows the temperature-time histories of sweet potatoes during RF heating at different electrode gaps. The total heating times required to heat the samples from 25 °C to 90 °C were 4.5, 8.5, and 14 min for sample thickness of 60 mm, at electrode gaps of 90, 100, and 110 mm, respectively. The heating rates decreased with increasing electrode gaps due to decreasing electric field intensity. The fastest heating rate (14 °C/min) was obtained when an electrode gap of 90 mm was used.

Fig. 5 shows the temperature-time histories of sweet potatoes during RF heating at different sample thicknesses using an electrode gap of 90 mm determined by the previous experiments. The results showed that thicker samples had a faster heating rate. The total heating times required to heat the sample from 25 °C to 90 °C were 4, 4.5, and 7.5 min

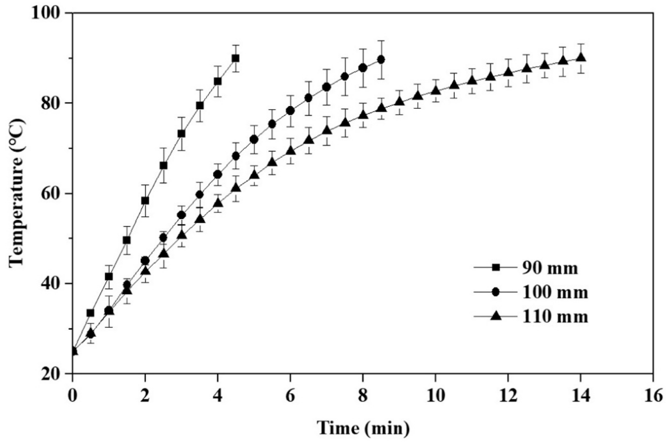

Fig. 4. Central average time-temperature histories of sweet potato samples subjected to radio frequency heating under different electrode gaps (90, 100, and 110 mm) at a fixed sample thickness of 60 mm and an initial temperature of 25 °C.

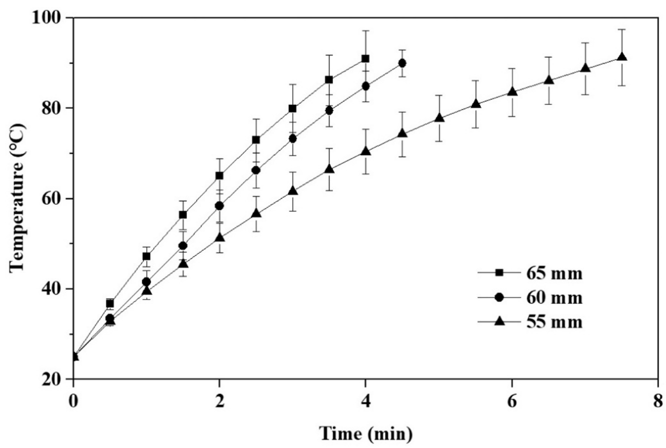

Fig. 5. Central average time-temperature histories of sweet potato samples subjected to radio frequency heating under different sample thicknesses (55, 60, and 65 mm) at a fixed electrode gap of 90 mm and an initial temperature of 25 °C.

for the electrode gap of 90 mm, at sample thicknesses of 65, 60, and 55 mm, respectively. The heating rates decreased with increasing electrode gap and decreasing sample thickness due to decreasing electric field intensity. Similar phenomenon was reported in RF treated apple slice (Zhang, Shi, et al., 2020).

3.2. Effects of electrode gaps and sample thicknesses on RF heating uniformity

Figs. 6 and 7 show the thermal images of samples at different electrode gaps and sample thicknesses, respectively. A temperature gradient was evident with maximum temperature at the core and minimum temperature at the subsurface. This core heating phenomenon may be attributed to the electric field behavior, which was deflected at the sample edges and concentrated at the central parts of the sample (Huang, Marra, & Wang, 2016). Besides, the heat loss on the surface of the sample may also be one of the reasons for the core heating pattern. A similar result was also observed in potatoes blanched by RF heating (Zhang, Guo, et al., 2018). Average sample temperatures were lower than 90 °C because of the heat loss when samples were taken out from the RF cavity, as well as during cutting and the photographing process.

Table 1 shows the average temperatures and the λ values of samples

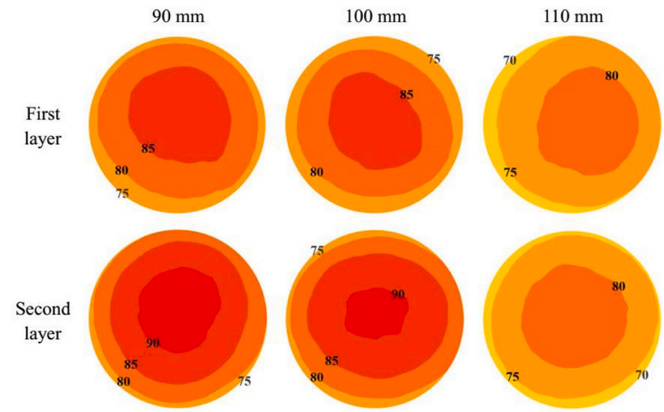

Fig. 6. Temperature distribution of sweet potato samples with two layers subjected to radio frequency heating under three electrode gaps (90, 100, and 110 mm) at a fixed sample thickness of 60 mm and an initial temperature of 25 °C.

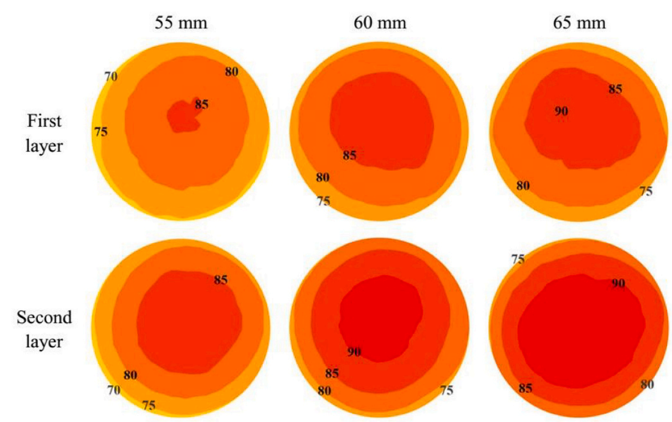

Fig. 7. Temperature distribution of sweet potato samples with two layers subjected to radio frequency heating under three sample thicknesses (55, 60, and 65 mm) at a fixed electrode gap of 90 mm and an initial temperature of 25 °C.

Table 1
The temperature and heating uniformity index (λ) (mean ± SD) of samples (60 mm thickness) on the first and second layers after RF heating for 4.5, 8.5, and 14 min at electrode gaps of 90, 100, and 110 mm, respectively.

Layer	Electrode gap (mm)	Temperature (°C)	λ
First	90	80.9 ± 0.5a[&]	0.068 ± 0.003ab
	100	79.4 ± 1.4a	0.072 ± 0.002a
	110	76.7 ± 0.5b	0.063 ± 0.001b
Second	90	82.6 ± 1.3a	0.078 ± 0.004ab
	100	81.9 ± 1.5a	0.080 ± 0.005a
	110	77.9 ± 1.5b	0.070 ± 0.002b

[&] Different lower-case letters within a column indicate that means are significantly different at $P < 0.05$ among different treatments for each layer.

on the first and second layers after RF heating under different electrode gaps. The temperature of the second layer was higher while the temperature distribution was more uniform at the first layer. The non-uniform temperature distribution could be due to the non-uniform distribution of the electromagnetic field (Huang et al., 2016). The electrode gap of 90 mm resulted in the fastest heating rate and an acceptable heating uniformity. Therefore, the electrode gap of 90 mm was selected for further studies.

Table 2 compares the average temperatures and the λ values of samples with different thicknesses after RF heating. There was significant difference ($P < 0.05$) on λ values of samples with different

Table 2
The temperature and heating uniformity index (λ) (mean ± SD) of samples on the first and second layers after RF heating (90 mm electrode gap) for 7.5, 4.5, and 4 min at sample thicknesses of 55, 60, and 65 mm, respectively.

Layer	Sample thickness (mm)	Temperature (°C)	λ
First	55	79.0 ± 0.9a[&]	0.081 ± 0.001a
	60	81.4 ± 0.4a	0.067 ± 0.002c
	65	80.1 ± 1.6a	0.075 ± 0.002b
Second	55	79.8 ± 0.5a	0.097 ± 0.001a
	60	82.8 ± 1.2a	0.078 ± 0.003b
	65	82.9 ± 2.4a	0.097 ± 0.002a

[&] Different lower-case letters within a column indicate that means are significantly different at P < 0.05 among different treatments for each layer.

thicknesses, the sample with a thickness of 60 mm showed the lowest λ value, indicating the best heating uniformity. To obtain both relatively rapid heating rate and appropriate heating uniformity, the sample thickness of 60 mm was selected for further studies.

3.3. Temperature-time histories of sweet potato during hot water blanching

Fig. 8 shows the temperature-time histories of sweet potatoes during HWB. The heating rate decreased with the increasing time. Besides, the subsurface temperature (Measurement point 5) increased faster than the central temperature (Measurement point 4). The temperature difference between the center and the subsurface of the sample increased first and then decreased with the increasing time due to the reduced temperature gradient between the medium and subsurface, and the maximum difference was about 10 °C when the sample was heated for 1 min. Similar phenomenon was also reported by Lilia et al. (2011) that the temperature difference between center and edge of carrot slice could reach 10 °C after hot water heating (90 °C) for 3 min. It is generally considered that the temperature difference between the center and the subsurface of the sample was mainly caused by the heat transfer from outside to inside during conductive heating (Guo, Mujumdar, & Zhang, 2019).

3.4. Effects of blanching methods on enzyme inactivation

Fig. 9 shows the relative POD activities of sweet potatoes after different blanching methods (hot water blanching and combination of RF heating with hot water blanching). The relative POD activity significantly ($P < 0.05$) decreased with increasing blanching time. After RF pre-heating (4.5 min) and holding process in hot water for 4, 6, and 8 min, the relative POD activities of samples decreased to 23.79%, 5.45%, and 0.00%, respectively. However, the relative POD activities of samples after 5, 10, and 15 min HWB were 63.84%, 20.87%, and

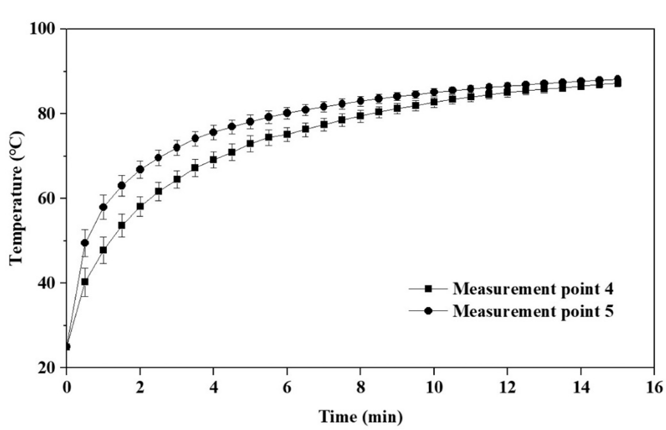

Fig. 8. Time-temperature histories of sweet potato samples at two locations subjected to hot water blanching (90 °C).

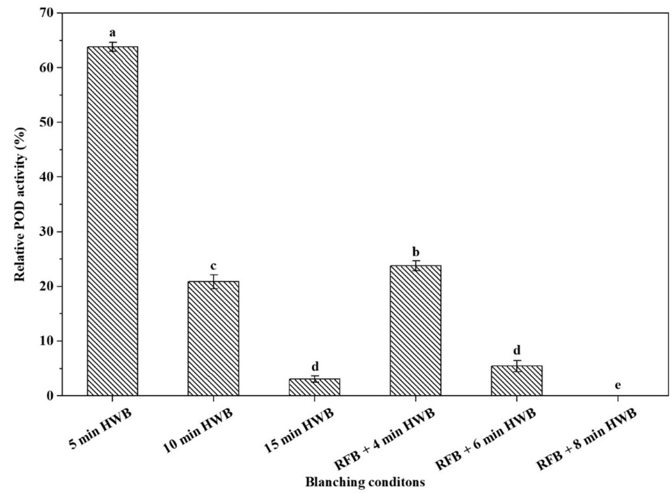

Fig. 9. Relative POD activities in sweet potato samples subjected to hot water blanching (HWB) and combined radio frequency with hot water blanching (RFB + HWB).

2.40%, respectively. Similarly, Gong, Zhao, et al. (2019) also observed that the RF blanching had better enzyme inactivation efficiency for carrots comparing with conventional method. The poor enzyme inactivation effect of HWB may be due to the slow heating rate. The heat carried by hot water takes time to transfer from the surface of the sample to the inside, so internal sample temperature cannot reach the expected temperature for enzyme inactivation. In this study, three treatment conditions (15 min HWB, 4.5 min RFB + 6 min HWB, and 4.5 min RFB + 8 min HWB) achieved the required level of enzyme inactivation (< 10%). Subsequent product quality analysis was conducted under these treatments.

3.5. Effects of blanching methods on moisture content and weight loss

The moisture content and weight loss of samples after blanching were listed in Table 3. The moisture content slightly increased with increasing blanching time in hot water. These results were not in agreement with RFB of rice bran (Ling, Ouyang, & Wang, 2019) and RFB of carrots (Gong, Zhao, et al., 2019) while they found a significant decrease in both moisture content and water activity of samples. This result might be attributed to the hot water holding period causing samples to absorb a small amount of water.

Samples lost some weights after all blanching treatments. This might be because the weight of lost water-soluble substances was greater than the weight of absorbed water. The weight loss of sweet potatoes treated by combined RF with hot water blanching was lower than that of samples blanched by HWB. Similar results were reported in water dropwort, showing that microwave blanching yielded lower weight loss than HWB (Tang et al., 2019). This could be due to prolonged contact of the sample with water during hot water blanching.

Table 3
Moisture content and weight loss (mean ± SD) of sweet potato samples subjected to hot water blanching (HWB) and combined radio frequency with hot water blanching (RFB + HWB).

Treatments	Moisture content (%, w.b.)	*WL* (%)
Control	64.89 ± 2.23b[&]	–
RFB + 6 min HWB	67.63 ± 1.68ab	0.72 ± 0.13b
RFB + 8 min HWB	67.29 ± 1.50ab	1.07 ± 0.30ab
15 min HWB	69.80 ± 1.92a	1.86 ± 0.46a

[&] Different lower-case letters within a column indicate that means are significantly different at P < 0.05 among different treatments.

Table 4
Color and texture values (mean ± SD) of sweet potato samples subjected to hot water blanching (HWB) and combined radio frequency with hot water blanching (RFB + HWB).

Treatments	Color				Texture		
	L^*	a^*	b^*	ΔE	Hardness (gf)	Frangibility (gf)	Chewiness (gf)
Control	56.89 ± 2.69a[&]	−3.08 ± 0.75a	21.84 ± 1.74a	–	1742.44 ± 25.51a	1094.93 ± 33.22a	168.19 ± 29.00a
RFB + 6 min HWB	51.61 ± 0.95b	−2.47 ± 0.41a	24.04 ± 1.37a	5.87 ± 0.96b	425.03 ± 27.34b	417.89 ± 31.29b	117.65 ± 35.51ab
RFB + 8 min HWB	50.93 ± 1.57b	−3.19 ± 0.69a	25.74 ± 0.55a	7.17 ± 1.49ab	223.04 ± 24.62c	208.14 ± 29.16c	67.32 ± 13.78bc
15 min HWB	48.11 ± 0.40b	−0.99 ± 2.28a	24.92 ± 2.53a	9.84 ± 1.67a	182.13 ± 19.92c	195.47 ± 30.85c	52.43 ± 10.95c

[&] Different lower-case letters within a column indicate that means are significantly different at $P < 0.05$ among different treatments.

3.6. Effects of different blanching methods on color and texture

Table 4 compares the color and texture of the sample after combined RF with hot water blanching and single hot water blanching. The value of brightness (L^*) generally decreased with increasing time of blanching treatment. However, the value of a^* and b^* increased with increasing temperature. This phenomenon was probably because cell collapse and the change of heat-sensitive components occurred during the process (Xanthakis, Gogou, Taoukis, & Ahrne, 2018). Similar changes were reported in RF blanching of potatoes (Zhang, Wang, et al., 2018) and microwave blanching of green asparagus (Dibanda et al., 2020). In addition, the lower value of ΔE was observed after RF preheating and 6 min hot water holding, indicating that combined RF with hot water blanching can better preserve the color of the samples. This phenomenon was probably due to the faster heating rate and shorter processing time. Similar results were reported in purple flesh sweet potato, showing that the sample after microwave blanching had a lower ΔE value than the sample after hot water blanching (Liu, Mujumdar, Zhang, & Jiang, 2015).

Hardness, frangibility, and chewiness significantly ($P < 0.05$) decreased after all blanching treatments (Table 4). This phenomenon was probably due to the damage of cell wall integrity, in turn may affect texture properties (Nguyen, Tran, Lam, Bach, & Nguyen, 2019). However, the hardness, frangibility, and chewiness of samples after hot water blanching were lower than those after RF blanching, indicating larger damage to the tissue of HWB treated sweet potatoes. Thus, the combined RF with hot water blanching can better maintain the texture of samples compared to the hot water blanching treatment.

4. Conclusion

The combined RF with hot water blanching including RF preheating and hot water holding was used for POD inactivation in sweet potatoes. POD activity of samples was reduced to 5.87% after RF preheating to 90 °C and 6 min holding in hot water (90 °C). The combined RF with hot water blanching was associated with shorter processing time (10.5 min) compared to hot water blanching (15 min). Moreover, better color and texture of sweet potatoes were observed after combined RF with hot water blanching, indicating that the combined RF with hot water blanching was an effective method for POD inactivation with less quality degradation. This study indicates that the combined RF with hot water blanching can be used as an effective method for POD inactivation and shows the potential of this technology for blanching vegetables and fruits. Future studies should be carried out to determine the effect of blanching treatments on the microstructure, subsequent processing and storage stability of sweet potatoes.

Author statement

HJ conducted experiment, analyzed data, and wrote the first version of manuscript. BL guided the experimental design and helped on analyzing potato quality. XZ assisted to conduct the experiments and improve the manuscript quality. SW is the PI of the project, guided the experimental design and revised manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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