

Article

Pilot-Scale Radio Frequency-Assisted Pasteurization of Chili Powders Prepacked by Different Packaging Films

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Abstract: Radio frequency (RF) can penetrate most packaging films and has the advantages of pasteurizing prepackaged low-moisture foods and avoiding secondary contamination. The suitable films for prepacking chili powders and the corresponding pasteurization process are unclear. This study aimed to select a suitable film for prepackaging chili powders, optimize the parameters of RF heating prepackaged chili powders, and evaluate the effects of RF-assisted pasteurization on the quality of chili powders. The results showed that the non-woven fabric (NWF) is suitable for prepackaging chili powders by evaluating the influence of RF heating on packaging films (appearance, sealing performance, mechanical properties.). Using NWF, chili powders inoculated with *Salmonella enterica* Enteritidis PT 30 still achieved 6.81 ± 0.64 log CFU/g reduction, treated by RF heating at an average temperature of 67.06 °C for 7.5 min with an electrode gap of 110 mm, held for 12.5 min at a hot-air convection oven. The pasteurization process had no significant ($p > 0.05$) effect on the quality (appearance, volatile, and capsaicin) of chili powders. The results indicated that chili powders packed with NWF could still be effectively pasteurized by RF-assisted hot air. This study proposed a viable approach to avoid secondary contamination by adding packaging before pasteurization.

Keywords: packaging materials; dielectric heating; spice; foodborne pathogen; disinfection



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1. Introduction

RF heating is a novel thermal processing technology that can generate heat inside foods by molecular friction caused by dipole rotation and ionic conduction, suitable for low-moisture foods (LMFs, foods with water activity at 25 °C < 0.85) [1]. RF has been applied to pasteurize wheat flour [2], canned pineapple [3], cumin seeds [4,5], red pepper powder [1,6], white pepper, and cumin powder [7]. Jeong et al. [8] found that RF heating can effectively inactivate *S. typhimurium* in red and black powders without generating heat injured cells that could recover. Li et al. [9] developed a model for the heating rate and heating uniformity of the RF pasteurization process of chili powder, in which the respective error value was 0.54% and 0.75% between the measured value and predicted value. Kim et al. [10] found that RF heating could serve as a heating step in combination with hot-air heating by thermal effect, including denaturation of enzymes, proteins, and nucleic acids and disruption of membranes. Uemura et al. [11] found that RF heating could be used to inactivate enzymes in packed miso paste; the results showed that phosphatases and proteases in packaged miso were completely inactivated by RF heating at 72 °C, 12 °C lower than conventional heating and two-thirds shorter in time, and a similar situation was found in packed tofu [12]. The above shows that RF heating still has a good pasteurization effect on packaged food samples. RF energy has a greater penetration depth and heating rate than traditional heat convection and conduction [13].

In the food industry, food packaging usually takes place after pasteurization. There is a time and space between pasteurization and packaging that gives food a chance for

secondary contamination with foodborne pathogens. We propose a prepackaging concept: food is packaged to a certain extent before pasteurization to minimize direct contact between food and the environment. Common films used in food packaging include Polyethylene (PE) [14], Polyethylene terephthalate (PET) [15], Polypropylene (PP) [16], Bamboo pulp paper (BPP) [17], and non-woven fabric (NWF) [18].

Demeczky et al. [19] found that RF pasteurization had a certain effect on sealed packaged juices, and the quality after pasteurization was better than that obtained by traditional pasteurization. Kong et al. [20] used composite materials to package carrot cubes and carried out RF-hot air combined pasteurization; the results showed that RF heating still had a significant pasteurization effect ($p < 0.05$) on the packaged samples and helped to maintain the quality of the finished products. Yang et al. [21] used an NWF film to wrap fried fries and effectively improve their softening. Researchers combined PE containers with wheat [22] and soybean [23], and the results showed that the introduction of PE material should not affect the heating patterns and temperature. Nonetheless, packaging films have different applicability to different foods. It is possible for the packaging film's properties to change when exposed to different processing conditions, which may affect the packaged food's quality [24]. In addition to meeting the basic packaging requirements, the packaging films required for food products should also perform well in RF heating and subsequent processing.

LMFs were considered microbial safe for the growth and reproduction of foodborne pathogenic microbial at a low water activity was inhibited [25]. The outbreak of foodborne pathogens in many LMFs (e.g., peanut butter [26,27], sunflower seeds [28], and nut cheese [29]) urged the intervention and validation of LMFs pasteurization. In particular, *Salmonella enterica* Enteritidis PT 30 appears to be the target pathogen in thermal process design and evaluation [30].

As a typical LMF, chili powder is the most-used seasoning in processed foods worldwide and plays a vital role in well-being, dietary habits, and boosting appetite [31]. Chili powders are typically processed in open environments, which provide ample opportunity for microbial contamination. Jeong et al. [32] reported that the detection percentage of contamination of *Bacillus cereus* in packaged red pepper powder was 39%, which was higher than the 8.1% detection rate in fresh red pepper. If spice processors could properly prepackage spice before pasteurization, this reordering of processing steps could theoretically reduce the risk of secondary microbial contamination. However, no scientific data on prepackaged chili powders on RF-assisted pasteurization have been reported.

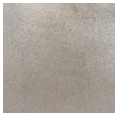
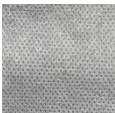
Therefore, the purpose of this study was to develop a practical pilot-scale RF-assisted hot air process for the pasteurization of prepackaged chili powders. The specific objectives of this study were to (1) select a suitable film for chili powders prepacking, (2) investigate RF-assisted hot air pasteurization for inactivation of *S. enterica* Enteritidis PT 30 in prepackaged chili powders, and (3) assess the effect of RF-assisted hot air pasteurization on the quality of prepackaged chili powders.

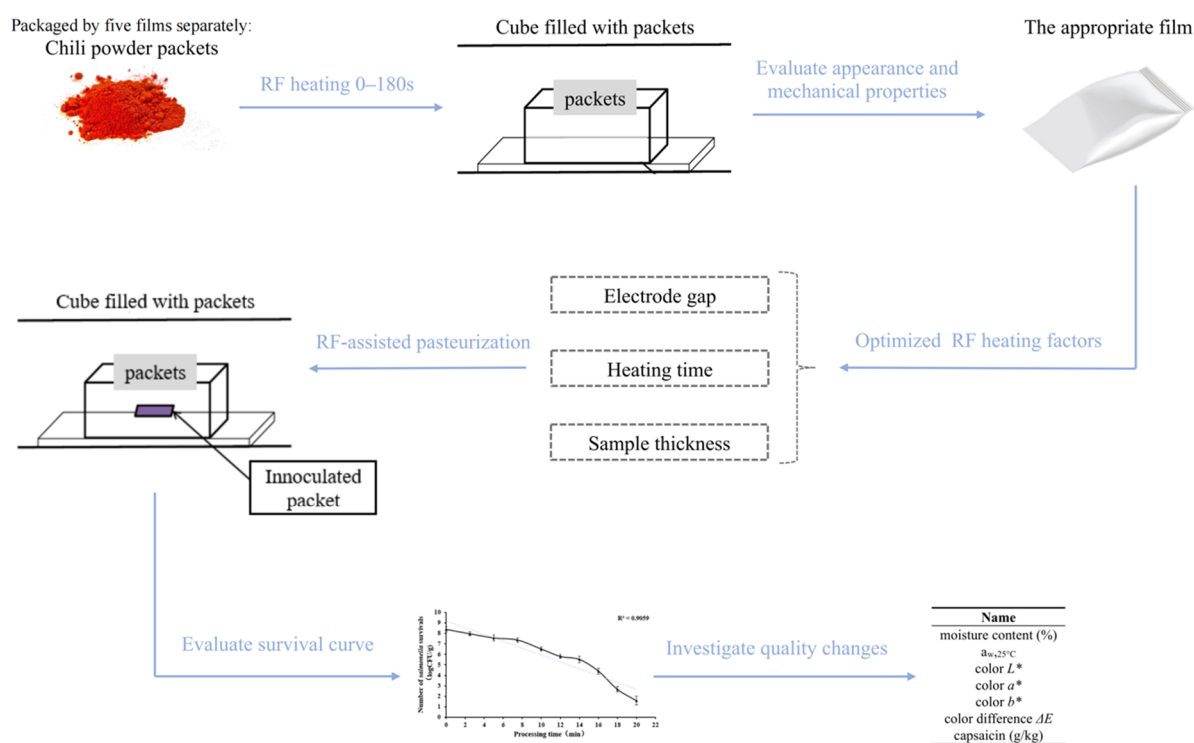
2. Materials and Methods

2.1. Materials and RF Apparatus

The basic information of the five films used for prepackaging tests is shown in Table 1, and the technical roadmap is shown in Figure 1. Film thickness was measured using a hand-held thickness gauge (547-301, Mitutoyo Measuring Equipment Co., Ltd., Tokyo, Japan), and water permeability rate was obtained according to the Chinese national standard GB/T 16928-1997.

Table 1. Appearance, thickness, permeable rate, and manufacturer of 5 films used for prepackaging.

Name	Appearance	Thickness (m)	Water Permeability Rate ($\text{gPa}^{-1}\text{s}^{-1}\text{m}^{-1}$)	Manufacturer
Polyethylene (PE)		5.60×10^{-6}	4.53×10^{-14}	Vanke Material Co., Ltd. Shanghai, China
Polyethylene terephthalate (PET)		7.13×10^{-5}	1.58×10^{-13}	Vanke Material Co., Ltd. Shanghai, China
Polypropylene (PP)		4.63×10^{-5}	5.46×10^{-14}	Vanke Material Co., Ltd. Shanghai, China
Bamboo pulp paper (BPP)		8.43×10^{-5}	2.29×10^{-12}	Xiangfeng Packaging Co., Ltd. Dongguan, China
Non-woven fabric (NWF)		2.09×10^{-4}	5.58×10^{-12}	Xinle Packaging Co., Ltd. Dongguan, China

**Figure 1.** The technical route. $a_{w,25^\circ\text{C}}$: water activity at 25 °C.

Chili powders (moisture content $4.71 \pm 0.03\%$) were purchased from a local market in Ya'an Sichuan, China. Materials for microbial tests were purchased from Qingdao Hopebiol-Technology Co., Ltd. (Qingdao, China). A pilot-scale RF heating apparatus (27.12 MHz, GJG-8B-2711-JY, Huashi Jiyuan Co., Ltd., Jiyuan, China) was used in the current study.

S. enterica PT30 (ATCC BAA-1045) was obtained from American type culture collection and stored in 20% glycerol at -80°C until use.

2.2. Evaluation of 5 Packaging Films in the RF Heating Process

The chili powders (250 g) were packed by PE, PET, PP, BPP, and NWF, respectively; each was processed on RF apparatus for 30, 60, 90, 120, 150, and 180 s (electrode gaps: 70 mm). By comparing the appearance, Young's modulus, tensile strength, and elongation at break of the packaging films after RF treatment, the influence of RF treatment on the appearance and mechanical properties of packaging films were investigated, and the prepacking materials suitable for RF heating of chili powders were screened.

The mechanical properties of five films after RF treatment were tested at room temperature using a material testing machine (TY8000—AF, Tianyuan Testing Equipment Co., Ltd., Yangzhou, China) according to Chinese National Standard GB/T 1040.3—2006. The films were cut into rectangular strips of 80 mm $\times$ 15 mm and mounted on a fixture for testing, with a clamping length of 60 mm and a testing speed of 100 mm/min. The measurements were stopped when the films broke.

Among the above indicators, Young's modulus measures the stiffness of the structure under the effects of unidirectional loading, which tends to stretch or compress it elastically [33]. Tensile strength (TS) refers to the maximum stress that a film can support before it breaks and is calculated from the tensile test by using the following equation [34]:

$$\text{TS} = F / (L \cdot x)$$

where F is the tensile force (N), L is the width of the film (mm), and x is the thickness (mm).

Elongation at break (%E) of the packaging film is the maximum elongation of the film before rupture, also calculated from the tensile test using equation [35]:

$$\%E = 100 \cdot (l - l_1) / l_1$$

where l_1 is the initial length and l is the film's length at the breaking point.

The mechanical properties of three replicate specimens in each film were measured, and the values were averaged. Non-treated films were used as the control.

2.3. Optimization of RF Heating Conditions

Prepackaged chili powders were added into a PP container (181 mm $\times$ 128 mm $\times$ 88 mm; Lock & Lock Co., Ltd., Suzhou, China), and the whole samples were placed on the bottom electrode for RF heating treatment. An orthogonal experiment was designed to model, improve and optimize the multiple variables based on the single-factor experiment results [36]. The uniformity index (UI) and average temperature (taking hot spot temperature and cold spot temperature into account) served as the investigation parameters. We measured three influential factors (the electrode gap, the heating time, and the thickness of the sample) in triplicate. In accordance with Liu et al. [37], sample temperatures were measured at various locations. Briefly, a set of nine thermocouples was inserted into the central layer of samples immediately following the RF heating treatment. Data were collected using a 12-channel temperature data logger (RDXL12SD; OMEGA Engineering Inc., Norwalk, CT, USA). Each measurement was taken three times.

2.4. RF-Assisted Pasteurization Process

S. enterica Enteritidis PT 30 was subjected to two consecutive transfers (24 ± 2 h each at 37°C) in 9 mL of tryptic soy broth supplemented with 0.6% (*wt/vol*) yeast extract (TSBYE), and then a TSAYE plate (150 $\times$ 15 mm) was evenly coated with 1 mL. With 20 mL of sterile 0.1% peptone water, we harvested the bacterial lawn on TSAYE, centrifuged it for 15 min at $5000 \times g$, 4°C , discarded the supernatant, and resuspended it in 3 mL of 0.1% peptone water. In accordance with the method of Chinese National Standard GB 4789.2-2016, the

concentration of the *S. enterica* Enteritidis PT 30 cell suspension obtained is approximately 10^7 – 10^8 CFU/mL.

After thoroughly hand-mixing *S. enterica* Enteritidis PT 30 cell suspension with chili powders in a sterile stomacher bag, the mixed sample was transferred to a constant temperature and humidity (25 °C, relative humidity 36%) chamber to reach the target water activity. Finally, a mixed sample ($a_w = 0.36 \pm 0.01$) was obtained and used in the following study.

We conducted preliminary tests to study the uniformity index and average temperature distribution of prepackaged chili powders under different conditions. The optimum set of factors was chosen with an orthogonal design combined with a multi-index test during the heating step. Once the RF heating procedure was complete, the container was tightly closed, moved to a preheated oven, and held for a certain amount of time. The control was the batch of prepackaged chili powders treated directly in the hot air oven at the same target temperature. Both RF-assisted hot air pasteurization and hot air pasteurization were performed in duplicate.

2.5. Quality Analysis of Chili Powders

The quality of chili powders was evaluated by determining moisture contents, water activity, color, capsaicin compounds, and volatile components. After the RF-assisted pasteurization heating process, the uninoculated samples were cooled at room temperature rather than in ice water to estimate the worst case of quality deterioration [38]. Only hot air heating was used in the control group.

Moisture content and water activity: Moisture contents of chili powders were measured using a halogen moisture meter (XFSFY-60A; Xiongfa Instrument Co., Ltd., Xiamen, China). Water activity was measured using a water activity meter (HD-3B; HuaKe Instrument Co., Ltd., Wuxi, China).

Color measurement: A colorimeter (SC-80, KangGuang Instrument Co., Ltd., Beijing, China) was used to determine the color of chili powders at three random locations by measuring the color values of L^* , a^* , and b^* . The total color difference (ΔE) was calculated using the following equation [39]:

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$

Capsaicinoid content: Capsaicinoid containing capsaicin and dihydrocapsaicin was determined about GB/T 21266-2007.

Volatile compounds: The volatile compounds analysis was performed referring to the method Garruti et al. [40] used. Extraction conditions: The extraction of volatile compounds was performed by manual headspace solid-phase microextraction (HS-SPME). A sample bottle containing 2.0 g chili powders was kept at 65 °C for 10 min, then the fiber (30 μ m divinylbenzene/carboxen/polydimethylsiloxane, Supelco Co., Bellefonte, PA, USA) was inserted, and adsorbed at 65 °C for 30 min. Then, the extracts were analyzed using a GC–MS system (Agilent Technologies, 7890A GC System, 5975C inert MSD with Triple-axis Detector, Santa Clara, CA, USA). Gas chromatography (GC) conditions: Chromatographic column: HP-5MS (30 m $\times$ 250 μ m $\times$ 0.25 μ m) elastic quartz capillary column; Heating procedure: 40 °C for 1 min, 5 °C/min to 150 °C, then 8 °C/min to 260 °C for 5 min; The carrier gas is helium (99.99%); Column flow rate: 1.00 mL/min; the split ratio is 5:1. Mass spectrometry (MS) conditions: Electron energy: 70 eV; Ion-source temperature: 230 °C; Contact surface temperature is 250 °C; The chromatograms were displayed by total ion chromatogram mode. Scanning range: 50–500 amu. For sample composition identification, NIST 11 mass spectral library was used. All measurements were performed in triplicate.

2.6. Statistical Analysis

The data were analyzed using Microsoft Excel 2019 (version 3.3.2, Microsoft office, Redmond, WA, USA), and all figures and tables were constructed in Microsoft PowerPoint 2019 (version 3.3.2, Microsoft office, Redmond, WA, USA) and GraphPad Prism

8.0 (version 8.0.2, GraphPad Software, San Diego, CA, USA). The microbial log reduction, moisture contents, water activity, and color values following RF treatments were subjected to a paired *t*-test. Statistically significant differences were found at the 95% confidence level ($p < 0.05$).

3. Results and Discussion

3.1. Influence of RF Heating on Packaging Films

The appropriate selection of food packaging should ensure that food does not undergo negative alterations to protect food and food products from potential damage and degradation [41]. The concept of “packaging first, then pasteurization” introduced in this study makes packaging films and food samples undergo thermal processing together, putting forward higher requirements for the performance of packaging films.

3.1.1. Appearance

The appearance of packaging films during RF heating is shown in Figure 2. After 30 s of RF heating, BPP was soaked by liquid, and after 180 s of RF heating, BPP was soaked more obviously and crumpled. This phenomenon may be due to the high thickness, low water permeability of BPP, and close combination of water/oil and bamboo pulp fiber so that the water generated in the heating process cannot be discharged in time. In addition, a certain amount of chili powders spilled from the BPP because the BPP film could not be sealed by hot-press. PET packaging expands during heating, and water is attached to the inner wall of the film. In the process of returning to room temperature, the water from the inner wall of the PET film gradually falls into the chili powders, causing it to “cake”, which is unacceptable for industrial production. A similar situation also occurs in PP film. When heated for 180 s, there is also a situation in which PP film is cracked (not sealed part) due to gas expansion in a particular experiment. When PE film was heated for 150 s, packaging expansion could be observed by the naked eye, but when heated for 180 s, the expansion phenomenon was almost not observed, which might be because the sealing degree of PE film was not as tight as PET film and PP film. Due to the air and water permeability of NWF film, there is no expansion of NWF film during the whole heating process. After unpacking, it was found that some chili powders adhered to the inner lining, which caused an inevitable loss. This phenomenon was improved after the sample was cooled to room temperature (25 °C). The mechanical properties of five packaging films were analyzed to explore the applicability of packaging films further.

3.1.2. Mechanical Properties

Mechanical properties, including Young’s modulus, tensile strength, and percentage of elongation at break, are crucial when packaging films are intended to withstand external processes while maintaining their integrity [42,43]. In the heating process, Young’s modulus of BPP, PET, PE, and PP meaningfully ($p < 0.05$) changed and varied in the range of 697.42–899.46 MPa, 461.41–688.90 MPa, 192.82–457.94 MPa, and 32.38–71.93 MPa, respectively (Figure 3a). Tensile strength of BPP, PE, and PP meaningfully ($p < 0.05$) changed and varied in the range of 15.47–25.21 MPa, 11.70–19.09 MPa, and 19.64–36.87 MPa, respectively (Figure 3b). Percentage of elongation at break of BPP, PE, and PP meaningfully ($p < 0.05$) changed and varied in the range of 4.00–5.77 MPa, 464.48–776.28 MPa, and 108.47–205.39 MPa, respectively (Figure 3c). We concluded that it is a complex change process in which three main factors and multiple factors work together to affect the film’s mechanical properties in different periods so that some mechanical properties have significantly changed. First, the influence of temperature on the films (broken hydrogen bond [44,45], interactions between polymers [46]); Second, the combination of released water, oil, and chili powder itself with the film; Third, uneven contact between the samples and the films and uneven structure of the films themselves.

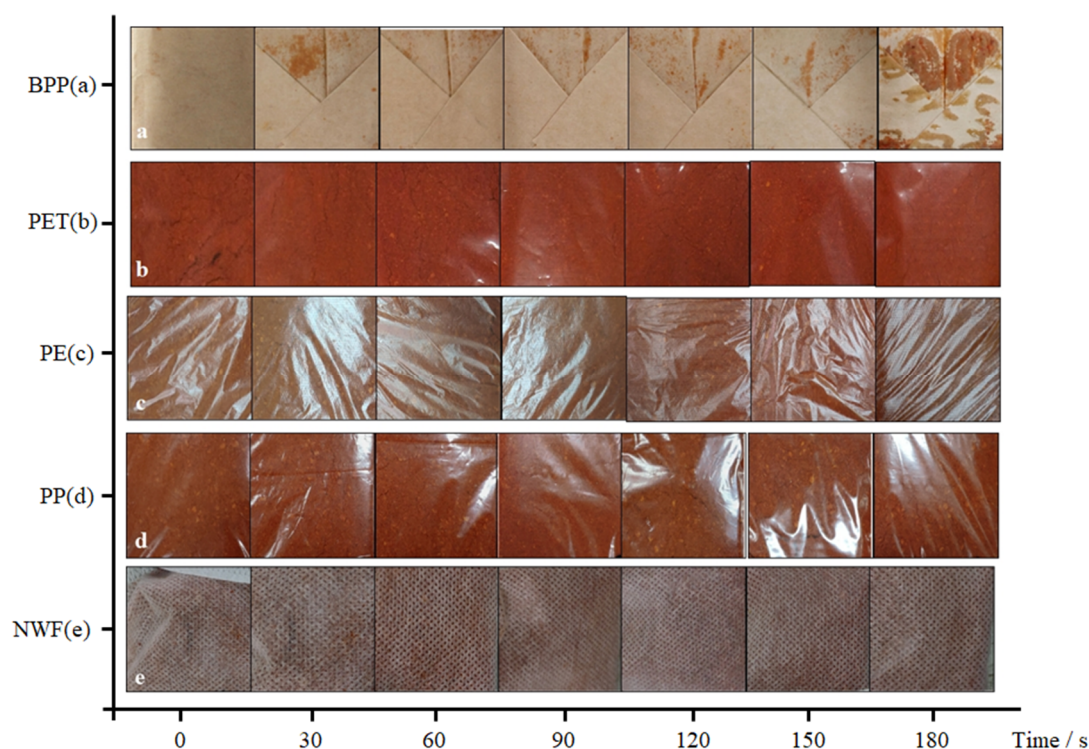


Figure 2. The process of packaging film's appearance changes during RF heating chili powders. (a–e) Five films, the heating period is from 0 to 180 s. In the process of heating, the packaging film is soaked (BPP), expands or even breaks (PET, PP), water droplets gather in the inner wall (PET, PP), and a small amount of powder is lost (BPP, NWF).

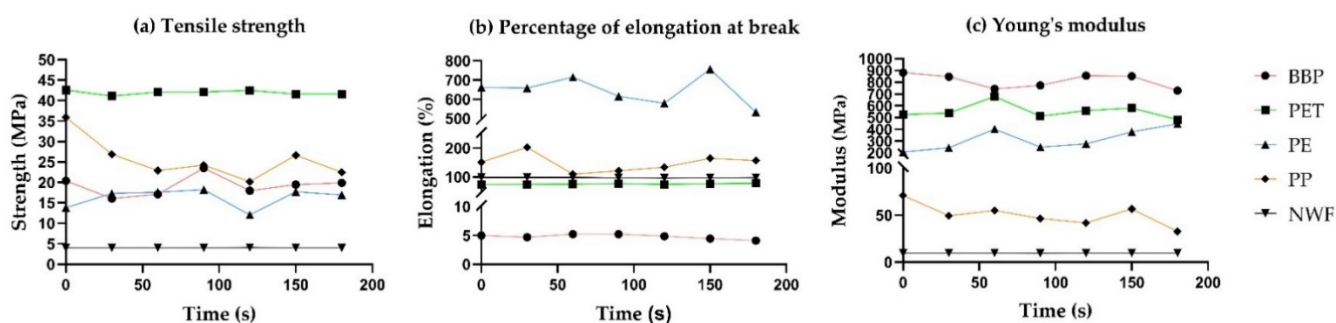


Figure 3. The effects of RF heating on packaging materials were evaluated by measuring the changes in (a) tensile strength of five materials within 0–180 s, (b) a percentage of elongation at break, and (c) Young's modulus.

In conclusion, the mechanical properties of NWF and PET were relatively stable during the heating process. Although PET has better results in tensile strength and percentage of elongation at break than NWF, considering that PET cannot discharge water and air in time during the process of “packaging first, then pasteurization”, NWF was finally selected as the prepackaging film in this study. It is important to note that NWF is used for prepackaging only. After the pasteurization of prepackaged products in actual production, it is necessary to determine whether to add additional outer packaging according to the comprehensive requirements.

3.2. Optimization of the RF Heating Process Using NWF

Three factors and three levels of the orthogonal design were determined on the basis of the previous single-factor experiment: sample thickness (50, 60, and 70 mm), heating time (350, 400, and 450 s), and electrode gap (100, 110, and 120 mm).

3.2.1. Range Analysis

With orthogonal experiments, range analysis was used to identify the significance levels of electrode gap distance, sample thickness, and heating time on two investigated factors (uniform index-UI, average temperature) [47]. Table 2 shows the results of L9 (3^3) orthogonal tests and summarizes the effects of three factors on the two investigated parameters.

Table 2. Orthogonal test factors, results, and statistical analysis: average temperature and uniform index (UI) used as investigated factors were measured and analyzed. K_i ($i = 1, 2, 3$): Mean of test results at different levels; R: The difference between the largest K_i value and the smallest K_i value in the same column.

Trial No.	Electrode Gap (mm)	Sample Thickness (mm)	Heating Time (s)	Average Temperature (°C)	UI (λ)
1	100	50	350	60.59	0.1826
2	100	60	400	62.42	0.1349
3	100	70	450	67.06	0.0946
4	110	50	400	60.05	0.1768
5	110	60	450	64.18	0.132
6	110	70	350	66.59	0.1192
7	120	50	450	59.44	0.1898
8	120	60	350	62.12	0.1389
9	120	70	400	64.95	0.1125
Average temperature (°C)	K_1	63.36	60.03	63.1	
	K_2	63.61	62.91	62.47	
	K_3	62.17	66.2	63.56	
	R	1.19	6.17	1.09	
UI (λ)	K_1	0.1374	0.1831	0.1469	
	K_2	0.1427	0.1353	0.1414	
	K_3	0.1471	0.1088	0.1388	
	R	0.0097	0.0743	0.0081	

The significance of three factors was determined based on the range analysis. The order of significance for the uniform index factor was sample thickness > electrode gap > heating time. The smaller the UI is, the more uniform the temperature distribution of chili powders after RF heating is, which is conducive to the uniform pasteurization and the quality control of chili powders [48]. Factors influencing average temperature were as follows: sample thickness > electrode gap > heating time, the average temperature of heated chili powders was higher for higher sample thicknesses, smaller electrode gaps, and longer heating times. For quality retention and decontamination, a combination of parameters that heats chili powders at a moderate temperature (55–70 °C) with a high UI would be ideal.

The change in sample thickness indirectly changes the distance between the geometric center of the sample (cold spot) and the pole plate on the RF equipment. As the thickness of the sample increases, it is observed that the current in the RF device becomes higher, the load increases, and the output power increases. In addition, it cannot be ignored that the inability to measure real-time temperatures during the experiments and the fact that different thicknesses of samples lose heat at different rates may also contribute to the thickness of the sample being a significant influencing factor.

3.2.2. Analysis of Variance

In Table 3, the sum of deviation squares (SS), degree of freedom (DF), and mean square deviation (MS) of the UI and average temperature were calculated. The results showed that the sample thickness had a significant ($p < 0.05$) effect on UI and an extremely significant ($p < 0.01$) effect on average temperature.

Table 3. Analysis of variance table: The influence of three factors on two investigated parameters was summarized. SS: sum of squares of deviation; DF: degree of freedom; MS: mean square deviation.

	Factors	SS	DF	MS	F	P
Average temperature (°C)	Electrode gap	3.5347	2	1.7673	12.9244	0.0718
	Sample thickness	57.2505	2	28.6252	209.3339	0.0048
	Heating time	1.7852	2	0.8926	6.5273	0.1328
	Error	0.2735	2	0.1367	-	-
UI (λ)	Electrode gap	0.0001	2	0.0001	0.7522	0.5707
	Sample thickness	0.0085	2	0.0043	45.2146	0.0216
	Heating time	0.0001	2	0.0001	0.5454	0.6471
	Error	0.0002	2	0.0001	-	-

Therefore, in the subsequent process of RF-assisted pasteurization, the following factors were used: electrode gap was 110 mm, sample thickness was 60 mm, and heating time was 450 s. Under this combination of parameters, the average temperature of chili powders after RF heating was 67.06 °C, the cold point temperature was 59.72 °C, and the heating uniformity index was 0.0946.

3.3. Inactivation Kinetics of *S. Enterica* Enteritidis PT 30 in Chili Powders

During pasteurization, the number of *S. enterica* Enteritidis PT 30 alive in the sample decreased linearly with the increase of RF treatment time (Figure 4). When the cold point temperature of the chili powders reached 59.72 °C in 450 s (7.5 min), *S. enterica* Enteritidis PT 30 was inactivated about 1.01 ± 0.43 log CFU/g. When the chili powders were placed in a hot air thermostat for holding 750 s (12.5 min), the lethal number of *S. enterica* Enteritidis PT 30 was 5.79 ± 0.62 log CFU/g. The remaining *S. enterica* Enteritidis PT 30 in the sample was 1.58 log CFU/g, which is less than the 2.70 log CFU/g required in the Chinese hygiene standard for ready-to-eat spices. The experimental survival curve of *S. enterica* Enteritidis PT 30 reached the 0 log CFU/g bacterial survival in a shorter time (22 min) than the predicted curve (25.91 min). It demonstrates that the treatment at 67 °C in an open system enabled a sharp reduction of microbial in prepackaged chili powders. The experimental result is similar to that of Ozturk et al. [49], who heated cornflour to 85 °C, held it for 10 min after heating in an RF system, and then stored it at −20 °C for 48 h, resulting in the reduction of *S. enterica* Enteritidis PT 30 by 6.59 ± 0.21 log CFU/g. Some researchers achieved a similar pasteurization effect in a shorter time [6,37,50]. This phenomenon occurred because we chose *S. enterica* Enteritidis PT 30 instead of *Salmonella typhimurium*, which has high D_{80} values in the extreme at a lower water activity [51]. Meanwhile, we chose a lower average temperature to maintain the quality of the chili powders [52].

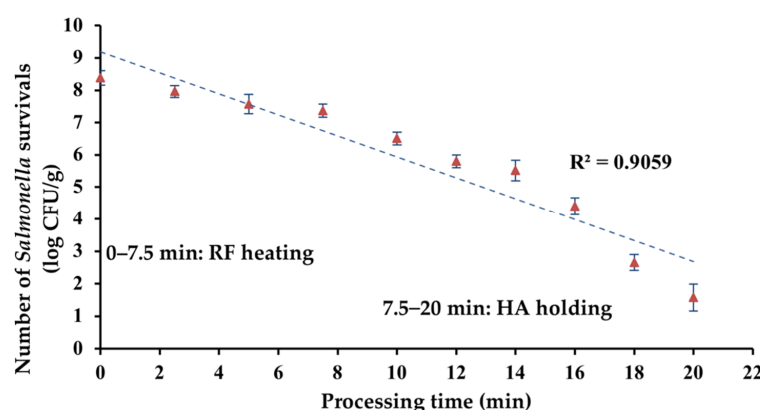


Figure 4. Survival curve and log-linear model of *S. enterica* Enteritidis PT 30 in prepackaged chili powders during a 20-minute RF-assisted hot air pasteurization.

3.4. Quality of Chili Powders before and after the Pasteurization

The quality of the chili powders was primarily determined by their moisture content, $a_{w,25^\circ\text{C}}$, color, capsaicin, and volatile compounds.

The $a_{w,25^\circ\text{C}}$ of the HA group's sample was 0.372 ± 0.014 with the moisture of $4.61 \pm 0.16\%$ (w.b.), RF heating would result in $a_{w,25^\circ\text{C}}$ significantly dropping to 0.330 ± 0.025 with the moisture of $4.44 \pm 0.15\%$ (w.b.) (Table 4). Significant changes in water activity were produced without significant changes in moisture content, which may be due to prolonged HA heating causing some of the bound water in chili powders to absorb energy and convert it into free water.

Table 4. Moisture content, water activity, color parameters, and capsaicin content of hot-air-heated (HA) and radio-frequency-assisted hot-air-heated (RF-HA) chili powders prepackaged by NWF.

Name	HA	RF-HA
moisture content (%)	4.61 ± 0.16^a	4.44 ± 0.15^a
$a_{w,25^\circ\text{C}}$	0.372 ± 0.014^a	0.330 ± 0.025^b
color L^*	27.43 ± 0.40^a	26.64 ± 0.42^a
color a^*	43.76 ± 0.20^a	43.79 ± 0.17^a
color b^*	47.12 ± 0.68^a	45.77 ± 0.73^b
color difference ΔE	-	1.5701
capsaicin (g/kg)	0.288	0.283

Within a line, there is no significant difference between numbers with the same superscript letter ($p > 0.05$). NWF: non-woven fabric film; $a_{w,25^\circ\text{C}}$: water activity at 25°C .

Color: The color of chili powder did not change significantly after the RF-HA treatment compared with hot air treatment alone. The calculated ΔE value is 1.57, indicating a normally invisible difference between samples treated with HA and RF-HA [53]. Ensuring that the color of spices does not change significantly is a matter of great importance for the thermal process. Schneider et al. [54] claimed that the thermal decontamination process, like the commercial steam treatment, had caused significant color loss of ground black pepper. The change of b^* value indicated that RF treatment affected the yellow pigment in the chili powders, and the effect of seeds in the chili powder during the measurement process could not be excluded. Changes in capsaicin were also minimal ($p > 0.05$).

Volatile compounds: There were 14 volatile compounds identified, and the 8 major components ($>4\%$ peak area) were D-limonene (52.13%), followed by β -myrcene (22.61%), b-thujene (15.69%), linalyl butyrate (6.66%), linalyl anthranilate (5.98%), β -linalool (5.70%), (Z)- β -ocimene (5.39%), and (10S, 11S)-himachala-3(12),4-diene (4.25%) in the HA treated samples (Table 5). The content of linalyl butyrate was significantly different ($p < 0.05$) between HA and RF-HA treatments, and so was (10S, 11S)-himachala-3(12),4-diene. The major volatile compounds were detected in both HA and RF-HA samples, as shown in Figure 5. General studies have shown that the introduction of RF energy leads to more loss of volatile compounds [55]. However, in this study, RF-HA treatment was more beneficial to the retention of volatile compounds in prepacked chili powders, which may be due to the introduction of packaging film to some extent to prevent the loss caused by rapid RF heating. There are minimal effects on the aroma of chili powders as a whole due to RF heating only affecting major volatile compounds in a more subtle manner than HA heating.

Table 5. Fourteen major volatile compounds of HA and RF-HA treated chili powders prepackaged by NWF. The differences of volatile compounds with significant changes were calculated.

Name	HA	RF-HA (Difference)
D-Limonene	52.13 ± 0.63^a	54.25 ± 7.54^a
β -Myrcene	22.61 ± 0.04^a	22.05 ± 0.52^a
b-Thujene	15.69 ± 14.22^a	8.26 ± 12.77^a
Linalyl butyrate	6.66 ± 0.32^a	7.77 ± 0.30^b (16.68%)

Table 5. Cont.

Name	HA	RF-HA (Difference)
Linalyl anthranilate	5.98 ± 0.24^a	6.08 ± 0.22^a
β -Linalool	5.70 ± 0.02^a	6.26 ± 1.24^a
(Z)- β -ocimene	5.39 ± 0.24^a	5.76 ± 0.83^a
(10S, 11S)-himachala-3(12),4-diene	4.25 ± 0.47^a	6.24 ± 0.60^b (46.80%)
β -Phellandrene	1.57 ± 0.02^a	2.01 ± 0.26^a
Cosmene	0.67 ± 0.25^a	0.85 ± 0.55^a
Dihydroactinidiolide	0.45 ± 0.01^a	0.71 ± 0.71^a
Anethole	0.40 ± 0.03^a	0.41 ± 0.06^a
Dodecane	0.36 ± 0.03^a	0.43 ± 0.02^b (20.73%)
10-Methyleicosane	0.45 ± 0.03^a	ND ^b (−100.00%)

Within a line, there is no significant difference between numbers with the same superscript letter ($p > 0.05$). HA: hot air; RF-HA: radio-frequency-assisted hot air; NWF: non-woven fabric.

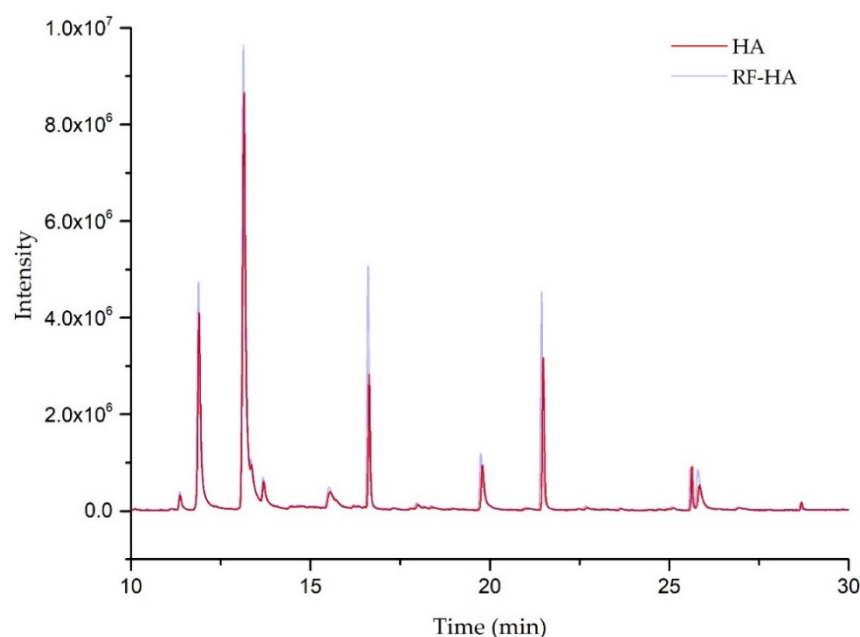


Figure 5. GC chromatograms of chili powders' main volatile compounds. The retention of almost all the main compounds after RF-HA treatment was superior to HA treatment.

4. Conclusions

In this study, for the “packaging first, then pasteurization” concept, the films and the optimal technology for pasteurization of prepackaged chili powders in RF were determined, and the pasteurization effect and the quality of the finished product were investigated. Indeed, NWF was the most suitable of these materials for prepacking chili powders in this study. RF uniformly heated 250 g prepackaged chili powders at the cold spot of 59.72°C within 450 s (sample thickness: 60 mm; electrode gap: 110 mm). After completing the heating and holding process, the chili powders reached 6.81 ± 0.64 log CFU/g reduction. At the same processing time, it was also demonstrated that there was no significant quality change between RF-assisted hot-air and hot-air pasteurization.

This study proposed a viable approach by adding packaging before pasteurization to avoid secondary contamination: “packaging first, then pasteurization”. Benefiting from the high penetration depth of RF energy, the concept of “package first, then pasteurization” can be implemented. Subsequent studies should investigate the effects of packaging films on the long-term storage of chili powders, screen more green films and composite films to increase the universality of “packaging first, then pasteurization”, and consider whether packaging films transfer harmful substances to food products during the heating process. In this study, only primary pre-packaging of chili powder was carried out, and subsequent

studies could attempt to process the food ingredients into a complete product followed by a pasteurization step, thus completely avoiding the possibility of the product being contaminated with pathogenic microorganisms.

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References

1. Zhang, H.J.; Zhao, Y.Y.; Gong, C.T.; Jiao, S.S. Effect of radio frequency heating stress on sublethal injury of *Salmonella* Typhimurium in red pepper powder. *LWT-Food Sci. Technol.* **2020**, *117*, 108700. [\[CrossRef\]](#)
2. Liu, S.X.; Ozturk, S.; Xu, J.; Kong, F.B.; Gray, P.; Zhu, M.J.; Sablani, S.S.; Tang, J.M. Microbial validation of radio frequency pasteurization of wheat flour by inoculated pack studies. *J. Food Eng.* **2018**, *217*, 68–74. [\[CrossRef\]](#)
3. Wang, Y.; Hou, Q.; Zhang, E.; Chen, Y.; Chen, X.; Wang, Y. Radio frequency pasteurization and heating uniformity of canned pineapple. *J. Food Sci.* **2022**, *87*, 2640–2650. [\[CrossRef\]](#)
4. Chen, L.; Wei, X.; Irmak, S.; Chaves, B.D.; Subbiah, J. Inactivation of *Salmonella enterica* and *Enterococcus faecium* NRRL B-2354 in cumin seeds by radiofrequency heating. *Food Control* **2019**, *103*, 59–69. [\[CrossRef\]](#)
5. Chen, L.; Irmak, S.; Chaves, B.D.; Subbiah, J. Microbial challenge study and quality evaluation of cumin seeds pasteurized by continuous radio frequency processing. *Food Control* **2019**, *111*, 107052. [\[CrossRef\]](#)
6. Zhang, B.; Zhang, L.; Cheng, T.; Guan, X.; Wang, S. Effects of water activity, temperature and particle size on thermal inactivation of *Escherichia coli* ATCC 25922 in red pepper powder. *Food Control* **2019**, *107*, 106817. [\[CrossRef\]](#)
7. Ozturk, S.; Kong, F.; Singh, R.K. Evaluation of *Enterococcus faecium* NRRL B-2354 as a potential surrogate of *Salmonella* in packaged paprika, white pepper and cumin powder during radio frequency heating. *Food Control* **2019**, *108*, 106833. [\[CrossRef\]](#)
8. Jeong, S.-G.; Kang, D.-H. 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.* **2014**, *176*, 15–22. [\[CrossRef\]](#)
9. Li, Y.; Zhang, Y.; Lei, Y.; Fu, H.; Chen, X.; Wang, Y. Pilot-scale radio frequency pasteurisation of chili powder: Heating uniformity and heating model. *J. Sci. Food Agric.* **2016**, *96*, 3853–3859. [\[CrossRef\]](#)
10. Kim, S.-Y.; Sagong, H.-G.; Choi, S.H.; Ryu, S.; Kang, D.-H. Radio-frequency heating to inactivate *Salmonella* Typhimurium and *Escherichia coli* O157:H7 on black and red pepper spice. *Int. J. Food Microbiol.* **2012**, *153*, 171–175. [\[CrossRef\]](#)
11. Uemura, K.; Takahashi, C.; Kobayashi, I. Inactivation of Enzymes in Packed Miso Paste by Radio-Frequency Heating. *J. Jpn. Soc. Food Sci. Technol.-Nippon Shokuhin Kagaku Kogaku Kaishi* **2014**, *61*, 95–99. [\[CrossRef\]](#)
12. Uemura, K.; Takahashi, C.; Kobayashi, I. Pasteurization of Packed Tofu by Radio Frequency Heating. *J. Jpn. Soc. Food Sci. Technol.-Nippon Shokuhin Kagaku Kogaku Kaishi* **2015**, *62*, 541–546. [\[CrossRef\]](#)
13. Tong, T.; Wang, P.; Shi, H.; Li, F.; Jiao, Y. Radio frequency inactivation of *E. coli* O157: H7 and *Salmonella* Typhimurium ATCC 14028 in black pepper (*piper nigrum*) kernels: Thermal inactivation kinetic study and quality evaluation. *Food Control* **2021**, *132*, 108553. [\[CrossRef\]](#)
14. Piscopo, A.; Zappia, A.; De Bruno, A.; Poiana, M. Qualitative variations on Calabrian Provolone cheeses stored under different packaging conditions. *J. Dairy Res.* **2015**, *82*, 499–505. [\[CrossRef\]](#)
15. Dhaka, V.; Singh, S.; Anil, A.G.; Naik, T.S.S.K.; Garg, S.; Samuel, J.; Kumar, M.; Ramamurthy, P.C.; Singh, J. Occurrence, toxicity and remediation of polyethylene terephthalate plastics. A review. *Environ. Chem. Lett.* **2022**, *20*, 1777–1800. [\[CrossRef\]](#)
16. Nguyen, H.L.; Tran, T.H.; Hao, L.T.; Jeon, H.; Koo, J.M.; Shin, G.; Hwang, D.S.; Hwang, S.Y.; Park, J.; Oh, D.X. Biorenewable, transparent, and oxygen/moisture barrier nanocellulose/nanochitin-based coating on polypropylene for food packaging applications. *Carbohydr. Polym.* **2021**, *271*, 12. [\[CrossRef\]](#)
17. Asensio, E.; Montañés, L.; Nerín, C. Migration of volatile compounds from natural biomaterials and their safety evaluation as food contact materials. *Food Chem. Toxicol.* **2020**, *142*, 111457. [\[CrossRef\]](#)
18. Ponnambalam, D.; Lim, L.T.; Manickavasagan, A.; Yucheng, F. Effect of heat-sealing parameters on the thermal profile and seal strength of multilayer films and non-woven. *Packag. Technol. Sci.* **2021**, *34*, 623–639. [\[CrossRef\]](#)

19. Demeczky, M. Continuous pasteurization of bottled fruit juices by high frequency energy. In Proceedings of the IV International Congress on Food Science and Technology, Madrid, Spain, 23–27 September 1974; pp. 11–20.
20. Kong, L.; Zhang, M. Impacts of RF-Hot Air Sterilizing on the Quality of Carrots in a Small Package. *J. Food Sci. Biotechnol.* **2015**, *34*, 943–948. (In Chinese)
21. Yang, F.X.; Wang, Z.Q.; Xu, T.; Jiang, Y. Study on Anti-Soft and Antibacterial Packaging Materials for French Fries. *Packag. J.* **2018**, *10*, 55–62. (In Chinese)
22. Huang, Z.; Zhang, B.; Marra, F.; Wang, S.J. Computational modelling of the impact of polystyrene containers on radio frequency heating uniformity improvement for dried soybeans. *Innov. Food Sci. Emerg. Technol.* **2016**, *33*, 365–380. [\[CrossRef\]](#)
23. Huang, Z.; Chen, L.; Wang, S. Computer simulation of radio frequency selective heating of insects in soybeans. *Int. J. Heat Mass Transf.* **2015**, *90*, 406–417. [\[CrossRef\]](#)
24. Zhao, W.; Tang, Y. Effects of lipid, PET/PE and PA/PE with high-pressure processing. *Int. J. Food Prop.* **2016**, *20*, 801–809. [\[CrossRef\]](#)
25. FDA. “Risk Profile: Pathogen and Filthn Spices” CFSAN Risk & Safety Assessments. 2019. Available online: <https://www.fda.gov/food/cfsan-risk-safety-assessments/risk-profile-pathogen-and-filthn-spices> (accessed on 18 January 2022).
26. FDA. Guidance for Industry: Measures to Address the Risk for Contamination by *Salmonella* Species in Food Containing a Peanut-Derived Product as an Ingredient. 2009. Available online: <https://www.federalregister.gov/documents/2009/03/11/E9-5367/guidance-for-industry-measures-to-address-the-risk-for-contamination-by-salmonella-species-in-food> (accessed on 18 January 2022).
27. CDC. Multistate Outbreak of *Salmonella* Typhimurium Infections Linked to Peanut Butter, 2008–2009 (FINAL UPDATE). 2009. Available online: <https://www.cdc.gov/salmonella/2009/peanut-butter-2008-2009.html> (accessed on 18 January 2022).
28. FDA. Urgent Food Recall of Jungle Jim’s Roast No Salt Sunflower Seeds, Windy Acres Fruity Trail Mix & Windy Acres No Salt Sunflower Seeds Due to Potential Presence of *Listeria Monocytogenes*. 2016. Available online: <https://www.fda.gov/Safety/Recalls/ucm504811.htm> (accessed on 18 January 2022).
29. CDC. Multistate Outbreak of *Salmonella* Braenderup Infections Linked to nut butter Manufactured by NSpired Natural Foods, Inc. (Final Update). 2014. Available online: <https://www.cdc.gov/salmonella/braenderup-08-14/index.html> (accessed on 18 January 2022).
30. Villa-Rojas, R.; Tang, J.; Wang, S.; Gao, M.; Kang, D.-H.; Mah, J.-H.; Gray, P.; Sosa-Morales, M.E.; López-Malo, A. Thermal Inactivation of *Salmonella enteritidis* PT 30 in Almond Kernels as Influenced by Water Activity. *J. Food Prot.* **2013**, *76*, 26–32. [\[CrossRef\]](#) [\[PubMed\]](#)
31. Byun, K.H.; Cho, M.J.; Park, S.Y.; Chun, H.S.; Ha, S.D. Effects of gamma ray, electron beam, and X-ray on the reduction of *Aspergillus flavus* on red pepper powder (*Capsicum annuum* L.) and gochujang (red pepper paste). *Food Sci. Technol. Int.* **2019**, *25*, 649–658. [\[CrossRef\]](#)
32. Jeong, A.R.; Jo, M.J.; Oh, S.-W.; Ku, K.-H.; Park, J.-B.; Kim, H.J. Microbiological Contamination of Fresh-Red Pepper and Pack-aged-Red Pepper Powder in South Korea. *Prev. Nutr. Food Sci.* **2010**, *15*, 233–238. [\[CrossRef\]](#)
33. Tan, J.C.; Cheetham, A.K. Mechanical properties of hybrid inorganic–organic framework materials: Establishing fundamental structure–property relationships. *Chem. Soc. Rev.* **2011**, *40*, 1059–1080. [\[CrossRef\]](#)
34. Antoniou, J.; Liu, F.; Majeed, H.; Zhong, F. Characterization of tara gum edible films incorporated with bulk chitosan and chi-tosan nanoparticles: A comparative study. *Food Hydrocoll.* **2015**, *44*, 309–319. [\[CrossRef\]](#)
35. Miller, K.; Krochta, J. Oxygen and aroma barrier properties of edible films: A review. *Trends Food Sci. Technol.* **1997**, *8*, 228–237. [\[CrossRef\]](#)
36. Cui, W.; Li, X.; Zhou, S.; Weng, J. Investigation on process parameters of electrospinning system through orthogonal experimental design. *J. Appl. Polym. Sci.* **2006**, *103*, 3105–3112. [\[CrossRef\]](#)
37. Liu, S.; Rojas, R.V.; Gray, P.; Zhu, M.-J.; Tang, J. *Enterococcus faecium* as a *Salmonella* surrogate in the thermal processing of wheat flour: Influence of water activity at high temperatures. *Food Microbiol.* **2018**, *74*, 92–99. [\[CrossRef\]](#) [\[PubMed\]](#)
38. Wei, X.; Lau, S.K.; Stratton, J.; Irmak, S.; Subbiah, J. Radiofrequency pasteurization process for inactivation of *Salmonella* spp. and *Enterococcus faecium* NRRL B-2354 on ground black pepper. *Food Microbiol.* **2019**, *82*, 388–397. [\[CrossRef\]](#) [\[PubMed\]](#)
39. Robertson, A.R. The CIE 1976 Color-Difference Formulae. *Color Res. Appl.* **1977**, *2*, 7–11. [\[CrossRef\]](#)
40. Garruti, D.D.S.; Mesquita, W.D.S.; Magalhães, H.C.R.; Araújo, M.D.S.; Pereira, R.D.C.A. Odor-contributing volatile compounds of a new Brazilian tabasco pepper cultivar analyzed by HS-SPME-GC-MS and HS-SPME-GC-O/FID. *Food Sci. Technol.* **2021**, *41*, 696–701. [\[CrossRef\]](#)
41. Umaraw, P.; Munekata, P.E.S.; Verma, A.K.; Barba, F.J.; Singh, V.P.; Kumar, P.; Lorenzo, J.M. Edible films/coating with tailored properties for active packaging of meat, fish and derived products. *Trends Food Sci. Technol.* **2020**, *98*, 10–24. [\[CrossRef\]](#)
42. Vieira, M.; Silva, M.; Santos, L.; Beppu, M.M. Natural-based plasticizers and biopolymer films: A review. *Eur. Polym. J.* **2011**, *47*, 254–263. [\[CrossRef\]](#)
43. Hosseini, S.F.; Rezaei, M.; Zandi, M.; Ghavi, F.F. Preparation and functional properties of fish gelatin–chitosan blend edible films. *Food Chem.* **2013**, *136*, 1490–1495. [\[CrossRef\]](#)
44. Jo, W.S.; Song, N.B.; Lee, J.H.; Song, K.B. Physical properties and antimicrobial activities of a persimmon peel/red algae compo-site film containing grapefruit seed extract. *Food Sci. Biotechnol.* **2014**, *23*, 1169–1172. [\[CrossRef\]](#)

45. Lu, W.Q.; Lu, L.X.; Tang, Y.L.; Yuan, L.; Pan, L. Impact of high-pressure processing on diffusion in polyethylene based on molecular dynamics simulation. *Mol. Simul.* **2017**, *43*, 548–557. [[CrossRef](#)]
46. Fu, Z.-Q.; Wang, L.-J.; Li, D.; Wei, Q.; Adhikari, B. Effects of high-pressure homogenization on the properties of starch-plasticizer dispersions and their films. *Carbohydr. Polym.* **2011**, *86*, 202–207. [[CrossRef](#)]
47. Zhao, L.; Zhao, Y.; Bao, C.; Hou, Q.; Yu, A. Optimisation of a circularly vibrating screen based on DEM simulation and Taguchi orthogonal experimental design. *Powder Technol.* **2017**, *310*, 307–317. [[CrossRef](#)]
48. Dag, D.; Singh, R.K.; Kong, F. Developments in Radio Frequency Pasteurization of Food Powders. *Food Rev. Int.* **2020**, *38*, 1197–1214. [[CrossRef](#)]
49. Ozturk, S.; Liu, S.; Xu, J.; Tang, J.; Chen, J.; Singh, R.K.; Kong, F. Inactivation of *Salmonella enteritidis* and *Enterococcus faecium* NRRL B-2354 in corn flour by radio frequency heating with subsequent freezing. *LWT-Food Sci. Technol.* **2019**, *111*, 782–789. [[CrossRef](#)]
50. Hu, S.Z.; Zhao, Y.Y.; Hayouka, Z.; Wang, D.F.; Jiao, S.S. Inactivation kinetics for *Salmonella typhimurium* in red pepper powders treated by radio frequency heating. *Food Control* **2018**, *85*, 437–442. [[CrossRef](#)]
51. Liu, S.; Tang, J.; Tadapaneni, R.K.; Yang, R.; Zhu, M.-J. Exponentially Increased Thermal Resistance of *Salmonella* spp. and *Enterococcus faecium* at Reduced Water Activity. *Appl. Environ. Microbiol.* **2018**, *84*, e02742-17. [[CrossRef](#)] [[PubMed](#)]
52. Cheng, T.; Wang, S. Modified atmosphere packaging pre-storage treatment for thermal control of *E. coli* ATCC 25922 in almond kernels assisted by radio frequency energy. *J. Food Eng.* **2018**, *246*, 253–260. [[CrossRef](#)]
53. Mokrzycki, W.S.; Tatol, M. Colour difference δE —A survey. *Mach. Graph. Vis.* **2011**, *20*, 383–411.
54. Waje, C.K.; Kim, H.-K.; Kim, K.-S.; Todoriki, S.; Kwon, J.-H. Physicochemical and Microbiological Qualities of Steamed and Irradiated Ground Black Pepper (*Piper nigrum* L.). *J. Agric. Food Chem.* **2008**, *56*, 4592–4596. [[CrossRef](#)]
55. Molnar, H.; Bata-Vidacs, I.; Baka, E.; Cserhalmi, Z.; Ferenczi, S.; Tomoskozi-Farkas, R.; Adanyi, N.; Szekacs, A. The effect of different decontamination methods on the microbial load, bioactive components, aroma and colour of spice paprika. *Food Control* **2018**, *83*, 131–140. [[CrossRef](#)]