Influences of pulsed light-UV treatment on the storage period of dry-cured meat and shelf life prediction by ASLT method

Na Liu^{1,2,3} · Qiujiu Zhu^{1,2,3} · Xuefeng Zeng^{1,3} · Bowen Yang^{1,3} · Meilian Liang^{1,3} · Ping Hu^{1,3} · Laping He^{1,3} · Li Deng^{1,3} · Cai Liang⁴ · Ruping Zhang⁴ · Juan Zhou⁴

Revised: 8 November 2018 / Accepted: 24 January 2019 / Published online: 9 March 2019
© Association of Food Scientists & Technologists (India) 2019

Abstract In order to prolong the shelf life of Chinese traditional dry-cured meat products, a pulsed ultraviolet light (PL-UV) irradiation method was adopted to treat meat products according to the following parameters: pulse energy of 8 J, 300 pulses, and an effective exposure distance of 10 cm; the UV light irradiation power of 6 W, an effective exposure distance of 11 cm, and an exposure period of 5 min. After a pulsed ultraviolet irradiation, total bacterial count in dry-cured meat decreased from 6.89 to 4.53 lg (CFU/g). The number of *Micrococcus* and *Staphylococcus* in samples decreased from 6.49 to 4.10 lg (CFU/g) and the number of *molds* and *yeasts* decreased from 5.45 to 4.28 lg (CFU/g). The number of *Lactic acid bacteria* increased from 3.97 to 4.55 lg (CFU/g) and *Escherichia coli* was not detected. Total colonies, target bacteria, peroxide value, thiobarbituric acid-reactive substances, water activity, T_2 relaxation time, pH, color difference, total volatile basic nitrogen, and the sensory evaluations of dry-cured meat products after PL-UV treatments were determined in a 30-d storage experiment. The shelf life of dry-cured meat treated with PL-UV

irradiation at 20 °C was predicted to reach to 294 d by applying of shelf life testing method accelerated. The quality and safety of dry-cured meat treated with PL-UV irradiation was better than that of untreated samples.

Keywords Dry-cured meat product · Pulsed light-UV · Antibacterial · Lipid oxidation · Quality

Introduction

Dry-cured meat is a popular meat product and accounts for a large proportion of processed meat products (Villalobosdelgado et al. 2014). It has different names in various countries, such as pastirma (Turkey, Egypt, and Russia), biltong (South Africa), cured meat (United States), charqui (South America), pemmican (North America), tasajo (Cuba), nikku (Canadian Arctic), cured and smoked pork loin (loin ham) (Japan), cured meat (China), carne seca (Mexico), and fenalår (Norway). Chinese dry-cured meat product is a non-instant meat product made from fresh (frozen) livestock meat and other auxiliary materials by pickling, drying, and smoking. It has obvious advantages, such as simple processing technique, special chewiness and flavor (Zhang and Zhao 2017), convenient storage and transportation, and rich nutrients. However, dry-cured meat products are easily contaminated by bacteria, which may lead to lipid oxidation and protein spoilage in the storage period (Asefa et al. 2010). In general, the spoilage mechanism of meat products is related to biochemical reactions involving internal enzymes and external microorganisms (Ruiz-Capillas et al. 2015; Wu et al. 2016). These spoilage bacteria include gram-negative aerobic bacteria (*Pseudomonas*, *Moraxella*, *Acetobacter*, *Aeromonas*, *Facultative anaerobic Enterobacteriaceae*, and *Alteromonas*

✉ Qiujiu Zhu
ls.qjzhu@gzu.edu.cn

✉ Xuefeng Zeng
heiniuzxf@163.com

¹ School of Liquor and Food Engineering, Guizhou University, Guiyang 550025, China

² School of Life Science, Guizhou University, Guiyang 550025, China

³ Guizhou Provincial Key Laboratory of Agricultural and Animal Products Storage and Processing, Guiyang 550025, China

⁴ Guizhou Wufufang Food Co., Ltd., Guiyang 550018, China

putrefaciens) and gram-positive bacteria (*Staphylococcus aureus* and *Brochothrix thermosphacta*) (Ruiz-Capillas et al. 2015). During the storage of dry-cured meat product, the bacterial community composition is changed and one or more bacterial species become the dominant bacteria and cause the spoilage.

Pulsed light sterilization belongs to non-thermal sterilization technologies based on instantaneous high-intensity wide spectrum pulsed light and has been widely applied in cereals, oil products, livestock products, poultry products, aquatic products, fruits, and vegetable products for its advantages of uniform sterilization, safe operation, and less environmental pollution (Kayalvizhi et al. 2016; Chen et al. 2015). Pulsed light disinfection treatment can realize the faster sterilization and lower residues than other sterilization methods, such as heating or using chemical disinfectants (Aguiló-Aguayo et al. 2013). The pulsed light technology can reduce *L. monocytogenes* and *S. typhimurium* on cured meat and sausage surfaces (Ganan et al. 2013). The continuous wave ultraviolet (UV, 200–400, NM) and high-intensity pulsed light (PL) technology as non-thermal methods of liquid foods (Koyyalamudi et al. 2011) have been widely applied in many fields. The technology can reduce the microbial contamination of fresh fruits and does not affect the nutritional value (Aguiló-Aguayo et al. 2013; Funes et al. 2013).

The ultraviolet radiation technology is characterized by high efficiency, easy operation and convenient management and has been applied in water treatment, hospital air disinfection, food packaging disinfection, and antibacterial treatment of beverages, fruits, vegetables, meat products, and sea foods. After the irradiation by short-wave ultraviolet radiation, DNAs of microorganisms break and the replication and cell division of DNA are inhibited, thus leading to cell death. These ingredients and nutritional values of fresh fruit juice, wine, cheese, milk, syrup, whey protein and egg could be maintained under the exposure to UV light (Koutchma 2014). Therefore, UV sterilization technology has a certain commercial value and can be applied in surface disinfection of fresh agricultural products and liquid products (Lagunas-Solar 2014) as well as the disinfection of air and water (Guan et al. 2015).

Both pulse light and ultraviolet radiation display some characteristics of surface antimicrobial technologies. However, the combination effect of the two technologies was not reported. In this study, the combined sterilization technology of pulsed light and ultraviolet radiation was used to treat Chinese traditional sliced dry-cured meat products and the feasibility of extending the shelf life by the PL-UV irradiation technology was explored.

Materials and methods

Materials

Dry-cured meat products were provided by Guizhou Wufufang Food Co., Ltd., China and processed with fresh pork meat, edible salt, wine and other spices. It was accord with the leave the factory of Guizhou Wufufang Food Co., Ltd. standards. Fresh pork meat was salted at 10 °C for 24 h and dried at (52 ± 2) °C for 20 h, followed by smoking and cooling. The dry-cured meat products were sliced into pieces with the size of 50 mm × 50 mm × 3 mm and the weight of 10.00–12.00 g. The samples were stored at 25 °C for the subsequent experiment.

In the experiment, dry-cured meat was divided into 4 groups: untreated group (Control), pulsed light and ultraviolet radiation group (PL-UV radiation), pulsed light radiation group (PL irradiation), and ultraviolet irradiation group (UV irradiation).

PL-UV light device

Pulsed ultraviolet light treatment device (Changzhou Lannuo Photoelectric Technology Co., Ltd. China) is composed of a power/control module, a processing chamber, a pulsed light xenon lamp and an UV lamp. There are one layer of steel pallet inside the chamber during the experiment, but the layer of steel pallet can be placed in different locations inside the chamber. A length of the PL-UV light chamber is 29 cm, the width of the chamber is 26 cm, and the irradiation area is 754 cm². The parameters of pulsed light tube are provided as follows: a length of 185 mm, a diameter of 8 mm, single pulse energy of 8 J, a pulse intensity of 7.8 mJ/m², a pulse frequency of 1 pulse/s. The parameters of ultraviolet lamp are provided as follows: a tube length of 185 mm, a diameter of 8 mm, lamp power of 6 W, and the effective wavelength of 254 nm. The processing chamber allows the vertical distance range from 2.35 cm to 17.80 cm, and UV energy ratio of 28.6%.

PL-UV light treatment and storage

Before the irradiation treatment, the UV light was on for at least 30 min to allow the constant power. There are one layer of steel pallet inside the chamber during the experiment. The dry-cured meat samples were evenly laid on the steel pallet of the PL-UV processing chamber. The single energy of dry-cured meat irradiated by pulsed xenon lamp was 8 J and the flashing time was 5 min. The power of the ultraviolet xenon lamp was 6 W. Dry-cured meat was 10 cm away from the pulsed light source. The distance of dry-cured meat away from the ultraviolet light source was

11 cm and irradiation time was 5 min. The vacuum packing meat was stored at 25 °C. The surface bacterial inactivation effect and the quality of dry-cured meat were determined in the subsequent storage period.

DNA extraction, amplification, sequencing and multivariate statistical analysis

The variable regions of prokaryotic 16S rDNA samples were amplified to identify the environmental prokaryotic microbial composition and abundance. The primers can effectively amplify 3 variable regions of 16S rDNA (V3, V4, and V5) and accurately identify various species of bacteria including archaea: forward primer 5'-CCTACGRRBGCASCAGKVRVGAAT-3' and reverse primer 5'-GGACTACNVGGGTWTCTAATCC-3' for V3 and V4 regions; forward primer 5'-GTGY-CAGCMGCCGCGGTAA-3' and reverse primer 5'-CTTGTGCGGKCCCCGYCAATTC-3' for V4 and V5 regions. PCR products were pooled and purified with the DNA Extraction Kit. Finally, the DNA library was constructed and run on the Miseq Illumina (Beijing Tops Biological Technology Co., Ltd, Beijing, China). The OTUs were identified by the partial least square discriminate analysis (PLS-DA) in Simca-P+ software (Version 12.0, Umetrics AB, Umeå, Sweden).

The high-throughput sequencing technology was employed (Fig. 1). The sequence error rate distribution is used to detect whether there is a high error rate in the base sequence. If the sequence error rate is expressed in e and the base mass value of Illumina HiSeqTM/MiSeq is expressed in Q_{phred} , we get the following relationships:

$$Q_{phred} = -10 \log_{10}(e) \quad (1)$$

Microbiological quality evaluations

The quantity of colonies was determined according to China National Food Safety Standard (GB 4789.2-2016): Aerobic Plate Counting, it was incubated 2 days at 37 °C, 25 g samples were homogenized with 225 mL Peptone Water Saline (PWS) composed of 0.85% NaCl; *Micrococcus* and *Staphylococcus* (Yantao et al. 2010): MSA medium inverted plate, it was incubated 48 h at 30 °C; *Molds* and *yeasts* were counted according to China National Food Safety Standard (GB 4789.15-2016): PDA medium inverted plate, it was incubated 5 days at 28 °C; *Lactic acid bacteria* were counted according to China National Food Safety Standard (GB 4789.35-2016): MRS medium inverted plate, it was incubated 72 h at 37 °C; *Escherichia coli* were counted according to China National Food Safety Standard (GB 4789.3-2016): VRBA medium

inverted plate, it was incubated 24–48 h at 37 °C. The samples tested in triplicate.

The germicidal effects of various factors on dry-cured meat were analyzed based on the experimental results. The inactivation rate was calculated according to the following formula (Cai et al. 2015).

$$Y = \frac{S - S_0}{S} \times 100\% \quad (2)$$

where Y is bacterial inactivation rate; S is the total number of colonies of dry-cured meat (CFU/g); S_0 is the total number of bacterial colonies in dry-cured meat treated with PL-UV light irradiation (CFU/g).

Peroxidation value and thiobarbituric acid-reactive substances

Peroxidation value (POV) was measured according to analysis method for determination of peroxide value in foods (GB/T5009.227-2016, China). extracting the fat of dry-cured meat by rotary evaporator (RE-2000A, Ya Rong Biochemical Instrument Factory, China). Each sample was measured 3 times to obtain the average value.. Thiobarbituric acid-reactive substances (TBARS) values were determined according to Bai's thesis (Bai et al. 2008). Take 10 g of minced dry-cured meat, add 50 mL of 7.5% trichloroacetic acid (containing 0.1% EDTA), shake for 30 min, filter twice with double-layer filter paper, and add 5 mL of supernatant to 5 mL of 0.02 mol/L TBA. The solution was incubated in a 90 °C water bath for 40 min, taken out and cooled for 1 h, centrifuged for 5 min (1600 r/min), and the supernatant was shaken with 5 mL of chloroform, and the supernatant remained unchanged. The absorbance values were colorimetrically determined at 532 nm and 600 nm to calculate the TBARS values:

$$\text{TBARS (mg/100 g)} = \frac{A_{532} - A_{600}}{155} \times \frac{1}{10} \times 72.6 \times 100 \quad (3)$$

Aw and NMR transverse relaxation time (T2)

The dry-cured meat samples (5–8 g) were evenly placed on the sample plate of the water activity tester to determine the water activity. The lean part was selected as far as possible for the determination. The A_w of the samples were measured according to the operation procedure of the instrument. Each group was measured three times in parallel. The NMR transverse relaxation properties of samples were measured on the MicrNMR magnetic resonance imaging analyzer PQ001 (Niumag MicroMR, China) (Mortensen et al. 2005). The proton resonance frequency was set as 23 MHz and the measurement temperature was

32.0 °C. T2 was measured with CPMG sequences. The parameters were set as follows: R value (the pulse duration between 90° and 180°) of 150 µs, repeated sampling times of 8, and repeated interval TR of 1800 ms. Exponentially decaying nuclear magnetic signals were adopted. The sample (1.0 g) was put into the sample tube with a diameter 12 mm. The tube was sealed to prevent moisture evaporation. Then the sample tube was placed in the nuclear tube in the analyzer. The CPMG sequence was used to detect the transverse relaxation of the samples. The relaxation signal is calculated as:

$$M(t) = \sum i P_i \exp(-t T_{2i}) \quad (4)$$

where P_i is the signal strength of the i th component; T_{2i} is the transverse relaxation time of the i th component in the sample. The total signal size is the sum of the sizes of the signals produced by all the components. The CPMG exponential decay curve was inversed by Multi-Explnv Analysis software. The synthetic iterative algorithm was adopted in the software. Based on the discrete and continuous T_2 spectra, corresponding measurement data were obtained.

pH and TVB-N

The pH measurements were conducted with a pH meter (Testo 205, Germany). Each sample was measured 3 times to obtain the average results. The samples (10 g) were minced and placed in a conical flask and then 100 mL of distilled water was added. The total volatile basic nitrogen (TVB-N) of samples was determined according to the modified Conway microdiffusion method (Li et al. 2012).

Color difference

A color difference meter (High-quality Colorimeter NH350, Beijing Western Yuanda Science and Technology Co., Ltd., China) was used to measure color changes of the samples during 30-d storage. The L^* values (black, white), a^* values (red, green), b^* values (yellow, blue) and ΔE were recorded in each test.

Sensory quality evaluations

Through the sensory scoring test, the color, odor and status indicators were obtained (Zhou et al. 2010). The sensory model score (scoring standards of sliced Larou) are shown in Table 1 (Health and Family Planning Commission 2015). In the scoring test, 10 food professionals were employed and they received the model of sensory evaluation related to the descriptive profile of sensory attributes (color, odor, and status of dry-cured meat) before testing.

Each panelist could thoroughly discuss and clarify each attribute to be evaluated. All the tests were carried out at controlled temperature under adequate lighting conditions without noise and odor. Four samples were tested by 10 referees for 6 times in 1 month (Day 5, Day 10, Day 15, Day 20, Day 25, and Day 30).

Shelf life model of dry-cured meat

According to the principle of accelerated shelf life test (ASLT), the ASLT method on the sensory basis was established by detecting the changes of POV in the storage period and the storage period at 20 °C (market storage temperature) was deduced. The POV should be no more than 0.5 g/100 g. We accelerated the prediction of shelf life based on ASLT method through the destructive experiment. The Q_{10} is calculated as:

$$Q_{10} = \frac{\theta_s(T)}{\theta_s(T + 10)} \quad (5)$$

where $\theta_s(T)$ represents the shelf life when the temperature is T , and $\theta_s(T + 10)$ represents the shelf life when the temperature is $(T + 10)$.

Then, the prediction formula for the shelf life of dry-cured meat is provided as:

$$Q_{10}^{\left(\frac{T_0 - T}{10}\right)} = \frac{\theta_s(T)}{\theta_s(T_0)} \quad (6)$$

where $\theta_s(T)$ represents the shelf life of dry-cured meat determined at the temperature is T ; $\theta_s(T_0)$ indicates the shelf life of dry-cured meat at T_0 in the acceleration test.

Data processing

The analyses of variance (ANOVA) and significance ($P < 0.05$) were performed with SPSS 13.0 software. Origin 8.0 software (Originlab Company) was used for data collection and mapping.

Results and discussion

Variations in total bacterial count during the storage

The variation of the total number of colonies in four groups of dry-cured meat products during the 30-d storage is shown in Fig. 2a. The total number of colonies of all the groups displayed an increasing trend during the storage. The value in the untreated group increased from 6.88 to 6.95 lg (CFU/g) ($P > 0.05$), which was higher than that in the PL-UV irradiation group [4.53 lg (CFU/g)]. Pulsed light irradiation prevented bacterial cells from replication (Koh et al. 2016). The total number of colonies in the PL

Table 1 Sensory scores of dry-cured meat products

Index	Scoring standard	Score
Color and lustre (10 points)	The muscle is the rose red or dark red, the fat is transparent and white; no mucus, no mildew	8–10 (excellent)
	The muscle is dark red or brown color, the fat color is transparent milky white; no mucus, no mildew	4–7.9 (commonly)
	The muscle is dark reddish brown or black, fat is yellow mucus, no mildew;	0–3.9 (bad)
Smell (10 points)	Cured has a strong flavor, no odor, no rancid flavor	8–10 (excellent)
	Cured has a good flavor, no odor, no rancid flavor	4–7.9 (commonly)
	Cured is light, it had a bad smell.	0–3.9 (bad)
State (10 points)	The tissue is tight and dense, Moderate hardness and without foreign body	8–10 (excellent)
	The tissue is tight and dense, the section is slightly fractured, and there is no foreign body	4–7.9 (commonly)
	The tissue is loose and loose and has foreign bodies	0–3.9 (bad)

Fig. 1 Sequencing experiment flow

irradiation group increased from 4.95 to 5.96 lg (CFU/g) ($P < 0.05$) and it increased from 5.15 to 6.31 lg (CFU/g) in the UV irradiation group ($P < 0.05$). Therefore, the antibacterial effect of PL-UV irradiation group was significant ($P < 0.05$).

The photochemical and photothermal effects of PL-UV irradiation group play a key role in the mechanism of sterilization (Liu et al. 2014). The nucleic acid in microbial cells absorbs a lot of ultraviolet light, forming the isomers of prodiazine and methyldiazine in the condition of PL-UV irradiation. Microbial metabolic dysfunction led to genetic problems and death. Water in cells could be vaporized instantly, thus leading to cell wall breaking and microorganism death within seconds under the condition of photothermal effects, rapid, high-energy, and intense pulsed light radiation. Pulsed light irradiation prevents bacterial cells from replication and division by changing bacterial DNA structure (Koyyalamudi et al. 2011). UV irradiation leads to the death of bacteria by inhibiting DNA replication and cell division. Several reports suggested that at the low light irradiation dose (Hormesis) ($B1 \text{ J/cm}^2$), the exposure of short-wavelength ultraviolet light (200–280 nm) for several minutes to 1 h induced a series of biochemical events in fresh agricultural products, displaying the

antimicrobial activity (Ribeiro et al. 2012). In this work, the parameters of PL-UV irradiation were set as follows: pulse energy of 8 J, 300 pulses, ultraviolet lamp power of 6 W, and the effective wavelength of 254 nm. After PL-UV irradiation, total bacterial count in dry-cured meat decreased from 6.89 to 4.53 lg (CFU/g) ($P < 0.01$).

Variations in target bacteria and bacterial phase during the storage

Through preliminary experiments, we identified the target bacteria in dry-cured meat. The number of *Micrococcus* and *Staphylococcus* increased in dry-cured meat during the storage period (Table 2). The number of *Micrococcus* and *Staphylococcus* in the Control increased from 6.49 to 6.87 lg (CFU/g) ($P > 0.05$). The reduction effects on *Micrococcus* and *Staphylococcus* were significant in PL-UV irradiation group ($P < 0.01$). In the PL and UV irradiation groups, the numbers of *Micrococcus* and *Staphylococcus* were maintained at about 4–5 lg (CFU/g). The numbers of *Micrococcus* and *Staphylococcus* in the 4 groups showed the following increasing order: PL-UV irradiation < PL irradiation < UV irradiation < Control. During the 30-d storage period, the number of *Micrococcus* or

Table 2 Target bacteria of dry-cured meat samples during the storage period

Name	Dry-cured meat/lg (CFU/g)	Date (d)					
		5d	10d	15d	20d	25d	30d
<i>Micrococcus</i> and <i>Staphylococcus</i> lg (CFU/g)	Untreated group	6.49 ± 0.31	6.58 ± 0.31	6.66 ± 0.25	6.67 ± 1.13	6.81 ± 0.53	6.87 ± 0.67
	PL-UV irradiation group	4.10 ± 0.13	4.29 ± 0.71	4.47 ± 0.51	4.56 ± 0.11	4.62 ± 0.92	4.68 ± 0.49
	PL irradiation group	5.27 ± 0.51	5.42 ± 0.36	5.54 ± 0.91	5.62 ± 0.42	5.69 ± 0.71	5.76 ± 1.56
	UV irradiation group	5.31 ± 0.12	5.46 ± 0.67	5.52 ± 0.89	5.65 ± 0.36	5.75 ± 0.51	5.80 ± 0.32
<i>Molds and yeasts</i>	Untreated group	5.45 ± 0.77	5.56 ± 0.34	5.64 ± 0.11	5.71 ± 1.01	5.76 ± 0.91	5.80 ± 0.52
	PL-UV irradiation group	4.28 ± 0.15	4.34 ± 0.81	4.47 ± 1.31	4.57 ± 0.42	4.66 ± 0.65	4.71 ± 0.53
	PL irradiation group	4.96 ± 0.58	5.06 ± 0.21	5.22 ± 0.17	5.29 ± 0.55	5.35 ± 0.81	5.40 ± 0.47
	UV irradiation group	5.13 ± 0.31	5.26 ± 0.58	5.29 ± 0.11	5.35 ± 0.25	5.41 ± 0.59	5.47 ± 0.81
<i>Lactic acid bacteria</i>	Untreated group	3.97 ± 0.51	3.85 ± 0.24	3.71 ± 0.59	3.33 ± 0.21	2.96 ± 0.37	2.76 ± 0.81
	PL-UV irradiation group	4.55 ± 0.11	4.31 ± 0.27	3.98 ± 0.91	3.84 ± 0.57	3.69 ± 0.36	3.47 ± 0.25
	PL irradiation group	4.06 ± 0.34	3.93 ± 0.11	3.82 ± 0.12	3.66 ± 0.27	3.41 ± 0.31	3.07 ± 0.39
	UV irradiation group	4.28 ± 0.13	4.02 ± 0.24	3.86 ± 0.07	3.76 ± 0.11	3.58 ± 0.37	3.27 ± 0.21
<i>Escherichia coli</i>	Untreated group	0	0	0	0	0	0
	PL-UV irradiation group	0	0	0	0	0	0
	PL irradiation group	0	0	0	0	0	0
	UV irradiation group	0	0	0	0	0	0

Staphylococcus showed no significant change. Lara et al. (2003) studied charqui (a traditional dry-cured beef in Brazil) and found that the number of *Staphylococcus* in beef decreased sharply after the sunlight exposure. Molina studied microbial changes during the processing process of dry-cured ham in rural areas, found that *Micrococcaceae* was the dominant bacteria in the pickling and ripening stages, and isolated 600 bacterial strains from the two stages, in which 99% *Micrococcus* existed and 90% of the *Micrococcus* was *staphylococci*. The numbers of *molds* and *yeasts* gradually increased during the storage period and the numbers of *molds* and *yeasts* in the PL-UV irradiation group were the smallest. The numbers of the *molds* and *yeasts* in the untreated meat group were the highest. *Lactic acid bacteria* decreased gradually ($P < 0.05$) along with the increase in pH and the decline in Aw in dry-cured meat. However, *Micrococcus* and *Staphylococcus* became the dominant bacteria and the order of magnitude was still between 5 lg (CFU/g) and 6 lg (CFU/g). *Escherichia coli* was not detected in 4 groups of dry-cured meat within 30-d storage (Fig. 2b). In addition, the irradiation treatment could kill *E. coli* under suitable pulsed light intensity (Chen et al. 2009). This study confirmed the significant bactericidal effect of PL-UV irradiation.

Variations in water activity and moisture distribution during the storage

The water activity reflects the content of free water. During the 30-d storage period, the water activity of 4 groups of dry-cured meat products increased in the following order (Fig. 2c): PL-UV irradiation < PL irradiation < UV irradiation < Control. The combined effects of pulsed light and ultraviolet radiation were more significant in reducing the water activity than those of single irradiation due to the radiation heat effect of PL-UV treatment (Taghvaei et al. 2015). The relationship between the inactivation rates and the water activities of dry-cured meat is shown in Fig. 3a. The linear relationship was negative ($r = -0.9963$, $P < 0.0001$). PL-UV irradiation treatment led to the higher inactivation rate and the lower water activity in dry-cured meat. The correlation between the inactivation rate and the water activity was significant and the water activity could be used as an index to evaluate the shelf life of dry-cured meat. The shelf life was correlated to the water activity. The lower the water activity was, the longer the shelf life was (Bovercid et al. 2012).

During the storage period, the water activity of the 4 groups of dry-cured meat showed an increasing trend (Fig. 3b) due to the gradual increase in the content of free water. According to the changing trend of the water

Fig. 2 Change of quality index of preserved dry-cured meat during storage

activity, 2 groups of cured meat samples were selected as the representative samples (PL-UV irradiation and Control group). Dry-cured meat treated with pulsed light and ultraviolet light showed the decreased peak area, indicating that the water movement was enhanced after PL-UV irradiation treatment. The proportion of each component calculated with the peak area indicated that after the pulse light UV treatment, the proportions of T_{20} (0.1–1 ms) and T_{23} (100–1000 ms) were respectively decreased by 2.0% and 7.5% ($P < 0.01$) and that the proportions of T_{21} (1–10 ms) and T_{22} (10–100 ms) were respectively increased by 2.8% and 7.4% ($P < 0.01$). The above changes indicated that the treatment with PL-UV irradiation changed the water distribution in dry-cured meat. The increase in bound water and the decrease in free water are significant, thus contributing the inactivation rate in the end (Colzato et al. 2011). The data indicated that the treatment of PL-UV irradiation changed the moisture distribution (increased bound water and decreased free water) in dry-

cured meat and eventually led to an extended shelf life by increasing the inactivation rate.

Variations in POV and TBARS during the storage

The peroxide value is an index reflecting the degree of lipid oxidation. Higher peroxide values indicate that the more intermediate products of lipid oxidation are accumulated, but these intermediates under oxidation conditions form small molecules. During the 30-d storage, the peroxide values of 4 groups of dry-cured meat showed an increasing trend (Fig. 2d). The peroxide value of the Control group increased from (0.062 ± 0.001) g/100 g to (0.077 ± 0.001) g/100 g ($P > 0.05$) and the peroxide value of PL-UV irradiation group increased from (0.064 ± 0.001) g/100 g to (0.079 ± 0.001) g/100 g ($P > 0.05$). The peroxide value increased firstly, then decreased, and finally increased. The strong pulsed light irradiation increased the peroxide value too. Due to a

Fig. 3 Correlation between the bacterial inactivation rate and A_w , T2 Relaxation characteristics after transverse magnetization decay signal inversion, Changes of the POV value of cured meat during storage (37 °C and 47 °C)

stable control of the radiation coefficient of PL irradiation, the peroxide value finally reached (0.075 ± 0.001) g/100 g. The peroxide value of PL-UV irradiation showed no significant difference compared to that of UV irradiation group ($P > 0.05$). The peroxide values in both groups were lower than that in the Control because the reasonable PL-UV irradiation reduced the peroxide value of lipid oxidation meat or stable meat products (Guizani et al. 2014). According to the method for determination of peroxide value in foods (GB/T5009.227-2016, China) of dry-cured meat, the peroxide value shall not exceed 0.5 g/100 g. After dry-cured meat was treated by vacuum packaging, the oxidation products significantly decreased and the shelf life of the product was extended, as indicated by Berdagué et al. (1993). Lipid peroxides are the main lipid oxidation products, which are usually unstable and may be rapidly decomposed or further oxidized into volatiles such as malondialdehyde and ketones (Jerkovic et al. 2007). The

TBARS values of 4 different groups are shown in Fig. 2e. TBARS values can reflect the final lipid oxidation degree because malondialdehyde is one of the ultimate products of lipid oxidation. TBARS can be concluded that some hydroperoxides degraded into thiobarbituric acid reactive substances in this stage (Huang et al. 2014). Malondialdehyde as a derivative of oxidative degradation of unsaturated fatty acids in oils and fats, can react with TBA to form stable red compounds. The higher the TBARS value, the higher the oxidation degree of fats (Pignoli et al. 2009). The TBARS value gradually increased during the storage period, indicating that the peroxides were gradually decomposed to form malondialdehyde, ketones, and other substances. The TBARS values of the 4 groups of dry-cured meat products increased since Day 15 and became stable at 0.54 mg/kg on Day 30. In the final stage, the TBARS tended to be stable due to the degradation or reactions related to malondialdehyde. Malondialdehyde or

Table 3 Variations of color difference of dry-cured meat during the storage period

Dry-cured meat	Index	Days					
		5d	10d	15d	20d	25d	30d
Control	L*	45.12 ± 0.37 ^a	45.6 ± 0.13 ^a	45.34 ± 0.44 ^a	44.42 ± 0.25 ^a	44.01 ± 0.27 ^a	43.51 ± 0.21 ^b
	a*	6.80 ± 0.55 ^a	7.63 ± 0.35 ^b	7.69 ± 0.62 ^b	8.11 ± 0.37 ^{bc}	8.38 ± 0.54 ^c	7.93 ± 0.51 ^b
	b*	3.71 ± 0.06 ^a	7.11 ± 0.16 ^c	7.89 ± 0.11 ^c	8.02 ± 0.08 ^d	7.04 ± 0.13 ^{bc}	6.65 ± 0.17 ^b
PL-UV irradiation	L*	45.43 ± 0.17 ^a	45.71 ± 0.41 ^a	45.93 ± 0.34 ^a	44.42 ± 0.39 ^b	44.01 ± 0.15 ^b	43.51 ± 0.26 ^c
	a*	7.80 ± 0.55 ^a	7.63 ± 0.61 ^a	7.52 ± 0.25 ^b	7.51 ± 0.39 ^b	7.72 ± 0.43 ^{bc}	7.88 ± 0.57 ^{bc}
	b*	6.85 ± 0.09 ^a	7.11 ± 0.21 ^b	8.32 ± 0.03 ^c	8.12 ± 0.09 ^c	7.55 ± 0.10 ^{bc}	6.92 ± 0.04 ^a
	ΔE	3.31	0.11	0.75	0.61	0.83	0.27
PL irradiation	L*	46.67 ± 0.33 ^a	45.66 ± 0.12 ^a	45.91 ± 0.14 ^{ab}	43.34 ± 0.19 ^b	43.45 ± 0.25 ^b	43.59 ± 0.39 ^b
	a*	8.65 ± 0.15 ^a	8.97 ± 0.36 ^a	9.31 ± 0.44 ^{bc}	8.72 ± 0.51 ^{ab}	9.11 ± 0.27 ^b	11.58 ± 0.62 ^c
	b*	6.38 ± 0.06 ^a	6.92 ± 0.02 ^a	7.23 ± 0.14 ^b	7.50 ± 0.18 ^b	8.25 ± 0.21 ^c	9.48 ± 0.13 ^d
	ΔE	3.60	1.35	1.84	1.34	1.52	4.62
UV irradiation	L*	44.26 ± 0.27 ^a	44.53 ± 0.32 ^a	42.86 ± 0.39 ^{ab}	43.66 ± 0.17 ^b	43.13 ± 0.24 ^b	42.36 ± 0.35 ^c
	a*	3.88 ± 0.33 ^a	4.57 ± 0.52 ^b	5.94 ± 0.59 ^c	6.31 ± 0.25 ^d	6.78 ± 0.36 ^d	7.31 ± 0.39 ^e
	b*	5.06 ± 0.02 ^a	5.28 ± 0.04 ^a	5.30 ± 0.06 ^a	5.49 ± 0.03 ^{ab}	6.91 ± 0.15 ^b	7.98 ± 0.11 ^c
	ΔE	3.33	3.72	3.99	3.20	1.83	1.86

Control is a standard, All values are mean ± standard deviation of three replicates (n = 9)

^{a-d}Means within a row with different letters are significantly different ($P < 0.05$)

their products as well as other compounds, such as amino acids and intermediates of Maillard reaction, endowed dry-cured meat with a special flavor (Prados et al. 2016).

Variations in color difference during the storage

The brightness values of 4 groups of dry-cured meat samples tended to decrease gradually and the color and freshness of dry-cured meat gradually decreased during the storage period (Table 3). The b^* value (yellowness) was related to the oxidation process of fat. The b^* (yellowness) of 4 groups of dry-cured meat samples increased gradually. In dry-cured meat treated with the light irradiation, This result and consistent the Kim's research that the a^* (redness) increased to black and b^* gradually increased (Kim et al. 2013). The a^* increased gradually, indicating the improvement in the color quality. The L^* (brightness) increased and the b^* decreased, indicating that the color quality of dry-cured meat declined. The b^* value can also reflect the oxidation degree of dry-cured meat, and the higher the b^* value is, the higher the degree of oxidation is. The b^* value in the PL-UV irradiation firstly increased, then decreased, and then increased and the peroxide value and the TBARS value also showed the same changing trend. As indicated by the changes of L^* , a^* , and b^* , the quality of the 4 groups of dry-cured meat samples decreased in the following order: UV irradiation > PL-UV irradiation > Control group > PL irradiation. The

irradiation increased the b^* value. The color changes of dry-cured meat were mainly caused by the decrease in surface water content and oxidation reactions of hemoglobin during the storage period. In the oxidation process of hemoglobin, nitrosylmyoglobin in dry-cured meat was induced by lactic acid bacteria to produce catalase and peroxidase. Wambura and Verghese (2011) indicated that UV irradiation promoted lipid acceleration and that pigments in dry-cured meat were oxidized. ΔE is defined as the total color difference of the sample, the larger the value of ΔE , the color difference is more. Control is a standard, The color difference of the 3 groups of dry-cured meat samples increased in the following order: PL-UV irradiation < PL irradiation < UV irradiation. PL-UV irradiation had a certain effect on L^* , a^* , b^* and ΔE values ($P > 0.05$).

Variations in pH during the storage

pH value is an important indicator of microbial spoilage in meat and meat products and affects the bacterial reproduction, color and water activity of meat products in the storage process (Yano et al. 1995). During the 30-d storage, the pH values of 4 groups of dry-cured meat samples showed an upward trend because meat proteins were decomposed into alkaline ammonia and amine compounds such as organic bases, which contributed to the reproduction of bacteria (Fig. 2f). The pH values of the PL-UV

irradiation and Control after 5-d storage were 6.03 ± 0.005 and 6.10 ± 0.01 , respectively. The pH values in the samples gradually became the alkaline value. During the storage period, ammonia and amine compounds in dry-cured meat gradually increased and the pH values of dry-cured meat samples gradually rose. However, the pH value of dry-cured meat sample treated by PL-UV irradiation was lower than that in the Control because irradiation inhibited the alkaline tendency.

Variations in TVB-N during the storage

TVB-N value, as the main hygienic index, indicates the freshness of meat products and reflects the spoilage degree of meat products (Rodtong et al. 2005). Protein degradation due to enzymes and microorganisms generates alkaline ammonia, amines and nitrogen-containing substances, such as volatile basic nitrogen compounds, which are small molecular substances and toxic non-protein nitrogen-containing compounds, such as metabolism products of amino acids and nucleotides. After 30-d storage, the TVB-N values of the Control, PL-UV irradiation, PL irradiation, and UV irradiation groups were respectively (18.9 ± 0.2) mg/100 g, (15.2 ± 0.6) mg/100 g, (16.1 ± 0.3) mg/100 g, and (17.5 ± 0.6) mg/100 g (Fig. 2g). The PL-UV irradiation could guarantee the stability of meat proteins because untreated dry-cured meat was more easily affected by microorganisms, moisture and other factors, thus resulting in the protein decomposition and the production of ammonia and amines. Intense pulsed light and UV irradiation lead to the decomposition of proteins and destroy protein integrity and muscle cell structure (Chen et al. 2009). The broken organelles released a large number of internal enzymes, which further accelerated protein degradation and the release process of the metabolism products of amino acids and nucleotides (Yang et al. 2017; Leygonie et al. 2012).

Variations in the sensory score during the storage

During the storage period, the sensory score of Control decreased rapidly and the sensory score of PL-UV irradiation was relatively stable because PL-UV irradiation treatment had little effect on the sensory score of the dry-cured meat samples (Fig. 2h). In the initial storage phase (0–10 d), the sensory score of untreated group was decreased by 0.25, but the decrease was not significant ($P > 0.05$). After 5-d storage, the sensory scores of 3 groups of samples were higher than that of the Control group. After 30-d storage, the sensory score of PL-UV irradiation group was 0.77 higher than that of Control ($P < 0.05$). The dry-cured meat products processed by PL-UV irradiation showed a certain flavor. The flavor of meat

products mainly came from lipid oxidation (Berdagué et al. 1993). Therefore, pulsed light or ultraviolet irradiation did not significantly change the sensory properties in dry-cured meat during the storage period and PL-UV irradiation could improve the flavor.

Pearson correlation coefficients

Pearson correlation coefficients between the sensory scores of dry-cured meat and physical and chemical indicators are provided in Table 4. Most of the correlation coefficients were greater than 0.9, indicating that the sensory index of dry-cured meat had the good correlation with physical and chemical indicators. The sensory score had a significant negative correlation with the total number of colonies, Aw, POV, TBARS, a^* , b^* , T21, T22, pH, and TVB-N ($*P < 0.05$; $**P < 0.01$) and a significant positive correlation with L^* and T21. The deterioration of dry-cured meat might be ascribed to microbial growth and fat oxidation during the prolonged shelf life. Fat oxidation barrier affected the growth of microorganisms. Therefore, the correlation coefficient between the total number of colonies and sensory score was less than that between the POV value and the sensory score. Fat oxidation was intensified and lipids were hydrolyzed to form free fatty acids, which were then oxidized into hydroperoxides and eventually decomposed into small molecules such as aldehydes and ketones (Pignoli et al. 2009), thus resulting in a high correlation between POV and TBARS values. Fat oxidation, microbial growth and other factors made the sensory score drop. The required physicochemical indices in Chinese Dry-Cured Meat Standard only include POV value and the correlation coefficient between POV value and the sensory score was the largest in this study. Therefore, the POV value could more precisely reflect the changes in the sensory quality of the dry-cured meat.

Prediction of the shelf life of dry-cured meat by ASLT method

Finally, the POV value was chosen as the key factor for predicting the quality change and shelf life of dry-cured meat during storage and the ASLT method was built as follows. The Q_{10} can be calculated with the acceleration test results in Fig. 3c, d. The reasons for the peroxidation value of dry-cured meat after PL-UV irradiation are less than the Control: First, the quality of the two types of bacon may be different; Secondly, it is related to the smaller parameters selected by the PL-UV instrument; Thirdly, It may be related to the influence of the total number of colonies on the peroxide value. The total number of colonies of Control is larger than that of the PL-UV irradiation group, which makes the Control

Table 4 Pearson correlation coefficient between sensory evaluation and physical–chemical indexes of dry-cured meat

	Sensory	Colonies	Aw	POV	TBARS	L*	a*	b*	T21	T22	T23	pH	TVB-N
Sensory	1	– 0.915*	– 0.965**	– 0.998**	– 0.989**	0.892*	– 0.796	– 0.841*	0.947**	– 0.602	– 0.935**	– 0.934**	– 0.958**
Colonies		1	0.971**	0.955**	0.937**	– 0.935**	0.801	0.409	– 0.952**	0.626	0.916*	0.926**	0.995**
Aw			1	0.929**	0.930**	– 0.940**	0.697	0.339	– 0.939**	0.598	0.946**	0.927**	0.972**
POV				1	0.870*	– 0.916*	0.683	0.903*	– 0.851*	0.455	0.909*	0.813*	0.963**
TBARS					1	– 0.945**	0.608	0.874*	– 0.840*	0.422	0.945**	0.828*	0.928**
L*						1	– 0.58	– 0.103	0.826*	– 0.444	– 0.893*	– 0.781	– 0.915*
a*							1	0.794	– 0.889*	0.884*	0.544	0.868*	0.787
b*								1	– 0.609	0.779	0.228	0.656	0.413
T21									1	– 0.817*	– 0.823*	– 0.992**	– 0.947**
T22										1	0.353	0.807	0.599
T23											1	0.830*	0.937**
pH												1	0.929**
TVB-N													1

Sensory refers to sensory score; colonies refers to the total number of colonies

peroxidation value larger, this has a certain relationship with the number of microorganisms and the production of enzymes. Strong microbial may affect the increase of peroxide value; Fourthly, the fat of dry-cured meat has a certain volatility, and the oil has a certain loss after PL-UV irradiation.

$$Q_{10}(\text{Control}) = \frac{\theta_s(T)}{\theta_s(T+10)} = \frac{49}{25} = 1.96$$

$$Q_{10}(\text{PL-UV irradiation}) = \frac{\theta_s(T)}{\theta_s(T+10)} = \frac{70}{30} = 2.33$$

It can be predicted when the temperature is 20 °C:

$$\theta_s(20)(\text{Control}) = 1.96^{\frac{47-20}{10}} \times 25 = 153 \text{ d}$$

$$\theta_s(20)(\text{PL-UV irradiation}) = 2.33^{\frac{47-20}{10}} \times 45 = 294 \text{ d}$$

According to the ASLT method, the predicted shelf life of the Control at 20 °C was 153 d. The predicted shelf life of PL-UV irradiation group at 20 °C was 294 d. In the actual storage experiment, the actual shelf life of the Control at 20 °C was 160 d and the actual shelf life of PL-UV irradiation group at 20 °C was 280 d. The predicted value was comparable to the actual value. There was a small difference between the predicted value and the actual experimental value, but it was not significant ($P > 0.05$). Therefore, the ASLT method can be used to predict the shelf life of dry-cured meat products. The method proved that PL-UV irradiation could prolong the shelf life of dry-cured meat (Fig. 3).

Conclusion

A pulsed light-UV irradiation method (PL-UV) was adopted to treat Chinese traditional dry-cured meat according to the parameter. The inactivation rate reached 99.59%. The inactivation rates of four groups were decreased in the following order: PL-UV irradiation > PL irradiation > UV irradiation > Control. Moreover, the water activity was related to the inactivation rate in dry-cured meat processed by pulsed UV irradiation. The indexes verified the feasibility and safety of this method. With the ASLT method, the shelf life of dry-cured meat with PL-UV irradiation at 20 °C was predicted to be 294 d. This method proved that the PL-UV irradiation technology could prolong the shelf life of dry-cured meat and improve the quality of dry-cured meat.

Acknowledgements This work is supported by the Natural Science Foundation of China (31660496), the Talents of Platform in Guizhou Province, China ([2016]5662), the Excellent Graduate Student Program Of Guizhou Province, China ([2015]6004-2), the Guizhou Graduate Special Food Processing Innovation Workstation, China (JYS[2015]009), and Project of the Innovation Fund for Graduate

Students of Guizhou University, China, Research Engineer (2017023).

References

- Aguiló-Aguayo I, Charles F, Renard CMGC, Page D, Carlin F (2013) Pulsed light effects on surface decontamination, physical qualities and nutritional composition of tomato fruit. *Postharvest Biol Technol* 86:29–36
- Asefa DT, Kure CF, Gjerde RO, Omer MK, Langsrud S, Nesbakken T (2010) Fungal growth pattern, sources and factors of mould contamination in a dry-cured meat production facility. *Int J Food Microbiol* 140:131
- Bai YH, You-Jun WU, Zhang X, Guo JL, Ren W, Wang GC (2008) Study on biological safety improvement of chilled meat treated by ultra-high pressure. *Sci Technol Food Ind* 6:99–101
- Berdagué JL, Monteil P, Montel MC, Talon R (1993) Effects of starter cultures on the formation of flavour compounds in dry sausage. *Meat Sci* 35:275
- Bovercid S, Belletti N, Garriga M, Aymerich T (2012) Response surface methodology to investigate the effect of high pressure processing on salmonella inactivation on dry-cured ham. *Food Res Int* 45:1111–1117
- Cai L, Cao A, Bai F, Li J (2015) Effect of ϵ -polylysine in combination with alginate coating treatment on physicochemical and microbial characteristics of Japanese sea bass (*Lateolabrax japonicus*) during refrigerated storage. *LWT Food Sci Technol* 62:1053–1059
- Chen GS, Lin HC, Wu MT (2009) Intense pulsed light irradiation may reverse activator protein-1 expression induced by ultraviolet b light. *J Am Acad Dermatol* 61:528–529
- Chen BY, Lung HM, Yang BB, Wang CY (2015) Pulsed light sterilization of packaging materials. *Food Pack Shelf Life* 5:1–9
- Colzato M, Scramin JA, Forato LA, Colnago LA, Obg A (2011) 1 h nmr investigation of oil oxidation in macadamia nuts coated with zein-based films. *J Food Process Preserv* 35:790–796
- Funes GJ, Gómez PL, Resnik SL, Alzamora SM (2013) Application of pulsed light to patulin reduction in Mcilvaine buffer and apple products. *Food Control* 30:405–410
- Ganan M, Hierro E, Hospital XF, Barroso E, Fernández M (2013) Use of pulsed light to increase the safety of ready-to-eat cured meat products. *Food Control* 32:512–517
- Guan M, Zhang J, Chen Y, Liu W, Kong N, Zou H (2015) Effect of uv irradiation, sample thickness and storage temperature on storability, bacterial activity and functional properties of liquid egg. *J Food Sci Technol* 52:4414–4422
- Guizani N, Rahman MS, Al-Ruzeiqi MH, Al-Sabahi JN, Sureshchandra S (2014) Effects of brine concentration on lipid oxidation and fatty acids profile of hot smoked tuna (*Thunnus albacares*) stored at refrigerated temperature. *J Food Sci Technol* 51:577
- Health and Family Planning Commission (2015) China Standard for Food Safety, cured meat products: G B2730—2015[s]. China Standard Press, Beijing, pp 1–2
- Huang Y, Li H, Huang T, Li F, Sun J (2014) Lipolysis and lipid oxidation during processing of Chinese traditional smoke-cured bacon. *Food Chem* 14:31–39
- Jerkovic I, Mastelic J, Tartaglia S (2007) A study of volatile flavour substances in dalmatian traditional smoked ham: impact of dry-curing and frying. *Food Chem* 104:1030–1039
- Kayalvizhi V, Pushpa AJS, Sangeetha G, Antony U (2016) Effect of pulsed electric field (PEF) treatment on sugarcane juice. *J Food Sci Technol* 53:1–9
- Kim SJ, Cho AR, Han J (2013) Antioxidant and antimicrobial activities of leafy green vegetable extracts and their applications to meat product preservation. *Food Control* 29:112–120
- Koh PC, Noranizan MA, Karim R, Nur Hanani ZA (2016) Microbiological stability and quality of pulsed light treated cantaloupe (*Cucumis melo* l. *reticulatus* cv. Glamour) based on cut type and light fluence. *J Food Sci Technol* 53:1798–1810
- Koutchma T (2014) Novel preservation applications of UV light. In: Preservation and shelf life extension, chap 7. Academic Press, London, pp 45–51
- Kooyalamudi SR, Jeong SC, Pang G, Teal A, Biggs T (2011) Concentration of vitamin D2 in white button mushrooms (*Agaricus bisporus*) exposed to pulsed UV light. *J Food Compos Anal* 24:976–979
- Lagunas-Solar MC (2014) Food technologies: pulsed ultraviolet radiation processing. *Encyclo Food Safety* 3:225–238
- Lara JAF, Senigalia SWB, Oliveira TCRM, Dutra IS, Pinto MF, Shimokomaki M (2003) Evaluation of survival of staphylococcus aureus, and clostridium botulinum, in charqui meats. *Meat Sci* 65:609–613
- Leygonie C, Britz TJ, Hoffman LC (2012) Meat quality comparison between fresh and frozen/thawed ostrich *M. iliofibularis*. *Meat Sci* 91:364–368
- Li T, Hu W, Li J, Zhang X, Zhu J, Li X (2012) Coating effects of tea polyphenol and rosemary extract combined with chitosan on the storage quality of large yellow croaker (*pseudosciaena crocea*). *Food Control* 25:101–106
- Liu L, Cao SQ, Chen W, Xiang-Yang QI, Yuan YJ (2014) Effects of pulsed light and ultraviolet-C irradiation on the activity of polyphenol oxidase from honey peach. *J Nucl Agric Sci* 28:85–90
- Mortensen M, Thybo AK, Bertram HC, Andersen HJ, Engelsen SB (2005) Cooking effects on water distribution in potatoes using nuclear magnetic resonance relaxation. *J Agric Food Chem* 53:5976–5981
- Pignoli G, Bou R, Rodriguezestrada MT, Decker EA (2009) Suitability of saturated aldehydes as lipid oxidation markers in washed turkey meat. *Meat Sci* 83:412–416
- Prados MD, Garcia-Perez JV, Benedito J (2016) Ultrasonic characterization and online monitoring of pork meat dry salting process. *Food Control* 60:646–655
- Ribeiro C, Canada J, Alvarenga B (2012) Prospects of UV radiation for application in postharvest technology. *Emir J Food Agric* 24:586–597
- Rodtong S, Nawong S, Yongsawatdigul J (2005) Histamine accumulation and histamine-forming bacteria in indian anchovy (*Stolephorus indicus*). *Food Microbiol* 22:475–482
- Ruiz-Capillas C, Tahmouzi S, Triki M, Rodríguez-Salas L, Jiménez-Colmenero F, Herrero AM (2015) Nitrite-free asian hot dog sausages reformulated with nitrite replacers. *J Food Sci Technol* 52:4333–4341
- Taghvaei M, Jafari SM, Nowrouzieh S, Alishah O (2015) The influence of cooking process on the microwave-assisted extraction of cottonseed oil. *J Food Sci Technol* 52:1138–1144
- Villalobosdelgado LH, Caro I, Blanco C, Morán L, Prieto N, Bodas R (2014) Quality characteristics of a dry-cured lamb leg as affected by tumbling after dry-salting and processing time. *Meat Sci* 97:115
- Wambura P, Verghese M (2011) Effect of pulsed ultraviolet light on quality of sliced ham. *LWT Food Sci Technol* 44:2173–2179
- Wu X, Song X, Qiu Z, He Y (2016) Mapping of tbars distribution in frozen-thawed pork using nir hyperspectral imaging. *Meat Sci* 113:92
- Yang Q, Sun DW, Cheng W (2017) Development of simplified models for nondestructive hyperspectral imaging monitoring of

- TVB-N contents in cured meat during drying process. J Food Eng 192:53–60
- Yano Y, Kataho N, Watanabe M, Nakamura T, Asano Y (1995) Changes in the concentration of biogenic amines and application of tyramine sensor during storage of beef. Food Chem 54:155–159
- Yantao WU, Cui C, Sun W, Yang B, Zhao M (2010) Effects of *Staphylococcus condimentii*, and *micrococcus caseolyticus*, on the volatile compounds of Cantonese sausage. J Food Process Eng 32:844–854
- Zhang J, Zhao X (2017) Changes in protein hydrolysates during processing of Chinese traditional dry-cured bacon (laròu) production. J Food Biochem 41:2
- Zhou GH, Xu XL, Liu Y (2010) Preservation technologies for fresh meat—a review. Meat Sci 86:119–128

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.