Radio frequency cooking of pork hams followed with conventional steam cooking

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Abstract

Radio frequency (RF) is a volumetric heating technology that reduces the time needed to cook foodstuffs, but heating is not evenly distributed. The aim of this work was to develop a two-step cooking process in a RF tunnel and in a steam oven (RF-ST) for pork hams and compare it to cooking in a steam oven (ST). The temperature distribution was monitored during cooking and the accumulated lethality was calculated. Cooking losses and physicochemical and sensory properties of the cooked product were analysed. Hot spots and overheating problems were identified during the RF cooking process and were reduced by shielding the ends of the hams with aluminium foil and by adjusting the times of both, RF and steam cooking. The total ST process time (360 min) was reduced by 50% in RF-ST (180 min). Hardly significant differences were observed in the technological and sensory quality of the final product. Regarding the food safety of the RF-ST process, the lowest accumulated lethality in RF-ST process was observed in the outer part of the hams, which can be increased by extending the ST processing time, obtaining a more evenly distributed accumulated lethality in comparison to the ST process.

Keywords: *Pork ham; Radio frequency cooking, Radio frequency overheating, Sensory quality.*

Highlights

- Cooking time decreased by 50% using radio frequency in large calibre products
- Best results obtained by combining radio frequency and steam cooking
- Overheating problems minimized by shielding the product ends
- Slight sensory quality differences observed between steam and RF-steam processes

1. Introduction

In conventional heating, heat penetrates through the surface and takes a long time to diffuse towards the centre of the product, resulting in a non-uniform heating. Radio frequency (RF) is a type of dielectric heating that generates heat volumetrically throughout the product using alternating electromagnetic fields. Dielectric heating has some advantages over conventional heating technologies, namely, higher heating rates, improved energy efficiency, heating of thicker products and a better distribution of temperature within the product (Singh & Ramaswamy, 2015). However, some problems can appear, such as thermal runaway heating, overheating (especially on the product edges) and dielectric breakdown (arcing) which can produce damages to both packaging and product (Zhao, Flugstad, Kolbe, Park, & Wells, 2000). There exist several solutions to address these problems, such as leaving an appropriate air gap between the top electrode and the foodstuff and/or immersing the product in water (Brunton et al., 2005; Lyng, Cronin, Brunton, Li, & Gu, 2007; Kirmaci & Singh, 2012). The immersion in distilled water increases the effective voltage applied to the product, thus increasing the heating rate, minimizing the incidence of electric arcs and discharges from the electrode (Kirmaci & Singh, 2012) and improving the uniformity of the temperature on the product surface. However, the use of water may also decrease the heating rate of the surface. Overheating in microwaves can be reduced by shielding the overheated parts of the food with metal films (Bohrer, 2009).

Cooked hams are some of the most consumed ready-to-eat meat products because of their high nutritional value and appreciated sensory attributes. Cooked meat products are thermally processed at 70-80 °C, using conventional heating technologies with steam or a water bath until reaching a core temperature of 66-72 °C. The RF has also proven effective in processing different types of meat products, such as pork ham and shoulder (Zhang, Lyng, & Brunton, 2006), chicken breast (Kirmaci & Singh, 2012), beef homogenate blends (Ganashree, Singh, Hung, & Mohan, 2015), non-intact beefsteaks (Rincon, Singh, & Stelzleni, 2015) or frozen chicken (Bedane, Altin, Erol, Marra & Edogdu, 2018), among others. In general, RF processing reduces considerably the processing time from around 40 % (Kirmaci and Singh, 2012) up to 90% (Laycock, Piyasena, & Mittal, 2003). All these studies have focused on RF cooking of products of small size/calibre (less than Ø100 mm and up to 1.2 kg), much smaller than the typical commercial size for cooked ham. Many of these studies relied on the use of hot water baths (around 80 °C) during the RF cooking to ensure heat distribution and temperature uniformity on the product surface. The main objectives of the present study were to: (1) develop a RF cooking process for large-calibre pork hams with a final conventional steam-cooking step to ensure complete cooking of the product (RF-ST), and subsequently (2) compare the thermal treatment and the sensory quality of the RF-ST cooking process with those of a conventional steam cooking process (ST).

2. Materials and methods

2.1. Pork ham preparation before cooking

Raw boned shoulders (boneless, without knuckles, skin and cartilage, well-polished and defatted) were obtained from a local meat processor. Refrigerated (48 h *post-mortem*) lean shoulders (35 kg/batch) were injected with a brine solution (22 g/100 g of raw meat) to give the following concentration of ingredients in the final product (g/100 g): 15.6 water, 1.9 NaCl, 0.45 tetrapotassium pyrophosphate, 0.06 sodium erythorbate and 0.023 sodium nitrite. Immediately after injection, the shoulders were minced with a three-hole kidney plate and mixed with 4 g/100 g of minced (Ø 3 mm) knuckle lean in a kneader mixer (50 l, Tecmaq) under vacuum for 1 h. Finally, the mass was vacuum-filled in polyamide/polyethylene waterproof plastic casings (230 mm Fibran Plex I, Fibran S.A., www.fibran.net) into 6.0 kg pieces (Ø146 mm and length ≈340 mm) and stored in refrigeration at 3 °C until next day, when they were cooked either with steam (ST) or with a combination of RF and steam (RF-ST).

2.2. Steam (ST) cooking

The conventional steam (ST) cooking of the pork hams was carried out in an oven (SCC101 Rational, www.rational-online.com). Hams were placed horizontally on the oven grids and were cooked with steam (100% RH) at a constant temperature of 72 ± 1 °C for approx. 6 h until reaching a core temperature of 68 ± 1 °C. These cooking parameters are commonly used in cooked ham processing in order to preserve the sensory characteristics of the product while obtaining pasteurization values (P_{70}) of 40-60 min and above (Feiner, 2006). Next, the cooked hams were cooled in a cold-water bath for 1 h and stored at 3 ± 1 °C until evaluation.

2.3. Radio frequency (RF) cooking

The RF cooking was carried out in a Radio Frequency system (RF 15 KW, STALAM S.p.A., Italy; www.stalam.com) with a maximum output of 15 kW (**Fig. 1**). The sample moved through two electrodes subjected to a voltage of about 5,300 V at a frequency of 27.120 ± 0.163 MHz. A staggered through-field electrode applicator with circular-shaped rod electrodes was used (Bedane, Altin, Erol, Marra, & Edogdu, 2018). The voltage of the upper electrode was set at 5,300 V and an electrode gap of 0.185 m (**Fig. 2**) was used. The conveyor belt speed was set at 10 m/h. The samples were individually cooked immersed in distilled water at 17 ± 2 °C with a 2.6:1 water to product weight ratio in a polypropylene container (L×W×H: 35×35×17 cm^3) with a 1-cm gap between the upper electrode and the container lid.

2.4. Preliminary tests to evaluate the temperature distribution in the hams after RF cooking.

The temperature distribution inside the hams was measured with a thermographic camera (PI160, Optris GmbH, Germany) after cutting the ham immediately after the RF cooking. This allowed defining the temperature positions to be monitored during the RF cooking.

2.5. Temperature measurements in ST and RF cooking

During the ST cooking process temperature was monitored and recorded at 10 s intervals with four (**Fig. 3**) Cu-CuNi thermocouples (type T, 405-382, TC Directand) connected to a data logger (Testo164/T4, Testo SE & Co. KGaA). During the RF cooking (**Fig. 4**), the temperature was measured at 1 s intervals with two optic fibre probes (FOT-L-NS-484B, FISO Technologies, Canada) connected to a data logger (TMI, FISO Technologies, Canada). The optic fibre probes were inserted through soft type septa (ref. 220235, Dansensor) to prevent vacuum leaks.

2.6. RF cooking with final ST cooking of hams

Prior to the RF cooking, both ends of the hams were covered with aluminium foil (**Fig. 4**) to minimize overheating (Bohrer, 2009). Hams were individually RF cooked until reaching a core temperature of 72 ± 1 °C. Since one cycle of RF cooking (10 min/cycle) was not enough to reach the target temperature, the container with the ham was pulled backwards to start a new cycle with the RF equipment switched on. This operation took approx. 30 s and the ham was all the time under the influence of the electric field. In order to improve the homogeneity of the heating process (Birla, Wang, & Tang, 2008), the RF cooking was stopped after 7 cycles to reverse the orientation of the ham manually (180° rotation along the transverse axis). Subsequently, the RF process continued until reaching the core temperature of 72 °C, which required 14 RF cycles in total (140 min processing time). Immediately after RF cooking, the aluminium foil shield was removed and hams were subjected to a conventional steam cooking (ST). The transfer time between the end of RF-cooking and the start of ST cooking was 3 min. The ST oven was preheated at 72 °C and 100% RH, and the steam cooking lasted approx. 40 min until a temperature of 68 ± 1 °C was reached by all the thermocouples monitoring the ham temperature. Next, the cooked hams were cooled down in a cold-water bath for 1 h and stored in a chilling room at 3 ± 1 °C until evaluation.

2.7. Comparison between ST and RF-ST cooking processes

Four batches of pork hams (seven hams per batch) were manufactured in four different days. Within each batch (manufacturing day), three hams were randomly assigned to the ST cooking process (n= 3x4 batches = 12 hams) and three hams to the RF-ST cooking process (n= 3x4=12), and one ham was left uncooked (n= 4) and used for the analysis of the chemical composition. The three hams within each batch were cooked together in the ST process. However, due to RF equipment capacity, hams were individually cooked in the RF-ST process. The temperature vs time profiles were monitored and recorded during cooking in two hams for each cooking process (ST and RF-ST) and batch. Some temperature probes failed during the cooking process and the records were discarded. The third cooked ham for each cooking process and batch (ST: n= 1x4 batches= 4 hams; RF-ST: n= 4 hams) was used to analyse the technological and the sensory quality.

2.8. Accumulated lethality calculation

In order to compare the RF-ST and ST cooking processes, the accumulated lethality was calculated from the time-temperature profiles during cooking. *Enterococcus faecium,* which has been involved in the spoilage of cooked meat products (Magnus, Ingledew, & McCurdy, 1986; Gordon & Ahmad, 1991), was selected as the reference microorganism for the calculations. The reference temperature (T_{ref}) was 70 °C and the thermal resistance z = 10 °C (Smelt & Brul, 2014). The accumulated lethality values (P_{70}^{10}) achieved in the ST and RF-ST processes were obtained by incorporating the experimental time-temperature profiles ($T_e(t)$), during the whole cooking process (RF and ST steps) into the lethality equation [eq. 1] and integrating the equation using the integration trapezoid method.

$$P = \int_{t=0}^{t=t_{total}} 10^{\left(\frac{T_e(t)-T_{ref}}{z}\right)} dt \qquad [1]$$

Where P is the accumulated lethality value (min), and t is time (min).

2.9. Physicochemical characteristics and cooking loss

The moisture, protein and fat contents (before and after cooking) were determined by near-infrared spectroscopy (Association of Official Analytical Chemists [AOAC], 2007) using a FoodScan™ Lab (Foss Analytical, Hillerød, Denmark). Chloride content was determined according to ISO 1841-2 (1996) using a potentiometric titrator 785 DMP Titrino (Metrohm AG, Herisau, Switzerland) and expressed as NaCl percentage. The pH of the minced raw and cooked pork hams was measured with a pH penetration electrode (Hach 52-33, Hach Lange GmbH, Düsseldorf, Germany) and a portable pH-meter (Portamess 913, Knick, Berlin, Germany). The cooking loss was calculated as the weight difference between raw weight and cooked weight (after draining and drying the ham surface), and expressed as a percentage of the raw ham weight.

2.10. Sensory analysis

A Quantitative Descriptive Analysis was performed. One ST and one RF-ST cooked hams from the same batch were evaluated in each session (one session per batch). The generation of the descriptors was carried out by open discussion in a previous session. The descriptors retained and their definition were: odour intensity (i.e., intensity of overall odour of the sample); cooked odour (i.e., intensity of cooked ham odour), flavour intensity (i.e., evaluation of the overall flavour intensity of the sample), sweetness (i.e., basic taste sensation elicited by sugar), saltiness (i.e., basic taste sensation elicited by NaCl), hardness (i.e., amount of pressure required to completely compress the sample), springiness (i.e., degree of return to the original position of the sample when a compression force is applied between molars), cohesiveness (i.e., textural property characterized by the difficulty with which a sample can be separated into particles during chewing) and juiciness (i.e., feeling of moisture inside the mouth as a result of chewing the sample). With respect to the texture properties of the slice, the outer zone of the slice (outer ring: width of 2 cm) and the inner zone (inner circle: diameter of 4 cm) were evaluated separately. Six trained panellists (American Society for Testing, Materials [ASTM], 1981; International Organization for Standardization [ISO], 1993, 1994) carried out the sensory analysis on 2 mm-thick slices. A non-structured scoring scale (Amerine, Pangborn & Roessler, 1965) was used, where 0 meant absence of the descriptor and 10 meant the highest intensity of the descriptor. Samples were wrapped in a film to avoid surface drying and evaluated within 1 h after slicing. Samples were coded with three-digit random numbers and were presented to the assessors balancing the first order effect (MacFie, Bratchell, Greenhoff, & Vallis , 1989).

2.11. Statistical analysis

The analysis of variance for the physicochemical parameters and sensory attributes was performed with the General Linear Model (GLM) procedure of the SAS statistical package (Statistical Analysis System [SAS], 2017). The average score of the panel for each cooked ham was used as dependent variable. The linear model included the cooking process (ST or RF-ST) as a fixed effect and the batch as a block effect. Differences among means were tested with the Tukey test.

3. Results and discussion

3.1. Temperature distribution in the hams after RF cooking

The temperature of the center of the ham just after finishing the RF cooking was quite homogeneous (50-55 °C) (**Fig. 5b**). **Fig. 5a** shows an uncooked outer layer in the ham which correlates with the low temperature isotherm lines (<40 °C) seen in the thermographic image (**Fig. 5b**). Thus, after RF cooking, the surface of the ham still showed a raw appearance, indicating insufficient heating of this part. Based on these results, ST cooking was carried out just after the RF cooking (RF-ST). The transfer time between the end of RF-cooking and the start of ST cooking was 3 min. Moreover, based on the thermographic image, the positions for the temperature probes (optic fibre and thermocouples) to monitor and record the temperature during the cooking processes, were defined (**Fig. 3**).

3.2. Temperature profiles of the ST and the RF-ST cooking processes

The time-temperature profiles of the hams at the core, at 2 cm below the surface and at the ends (**Fig. 3**, probe positions P2, P3 and P4) are shown in **Fig. 6**. After 360 min of cooking, the ST hams reached 68 °C at P2 (**Fig 6a**), whereas the final temperature was slightly higher (70 °C) at P3 and P4. As expected, the ST heating was much faster at the ends and near the surface of the product than at the core, as the heat penetrates by conduction from the outside of the product. The RF-ST hams reached 72 °C at P2 after 140 min of RF cooking (**Fig. 6b**). While the temperature at P4 was 75 °C, only 3 degrees higher than at P2. This confirms that the aluminium shielding helped to prevent overheating of the ham ends during RF cooking. In contrast, the temperature at position P3, which was only recorded just at the end of RF cooking, was much lower (60 °C). Thus, the temperature difference measured after RF cooking between P2, P3 and P4 was approximately 15 °C.

The steam-cooking of the RF-ST process lasted 40 min, until the temperature at P3 (the coldest point after RF-cooking) reached 68 °C. During the steam cooking, the heat diffused from the hottest to the coldest spots and, at the same time, the steam heat penetrated from the surface. The temperature decreased from 72 °C to 68 °C at P2 and from 75 °C to 70 °C at P4. In contrast, the temperature at P3 increased from 60 °C to the target temperature (68 °C). The total cooking time of the RF-ST process was approximately half that of the conventional ST process, 180 and 360 min respectively.

Several studies with meat products have reported cooking times with RF significantly lower than with conventional processes. Zhang, Lyng, & Brunton, (2006) reported a cooking-time reduction by 75% for pork leg and shoulder, and by 79% for a similar comminuted meat product (Zhang, Lyng, & Brunton, 2004). In other products, such as beef, the reduction was 90% (Laycock, Piyasena, & Mittal, 2003), and 73% in turkey rolls (Tang, Cronin, & Brunton, 2005). For chicken breast, with a higher weight (between 1.36 kg and 2.27 kg) than previous studies, the reduction was 42.4% (Kirmaci & Singh, 2012), similarly to the value observed in our study. In this case, the samples were immersed in water at 20 °C, similarly to this study and samples were bigger than in other studies. This may explain the lower reduction in cooking time.

3.3. Accumulated lethality of ST and RF-ST cooking processes

The accumulated lethality values (P_{70}^{10}) varied greatly from 50 min to 165 min for the ST hams (**Fig. 6a**), and from 22 min to 106 min for the RF-ST cooked hams (**Fig. 6b**). The difference between the maximum and minimum P_{70}^{10} values for the ST hams was higher (115 min) than for the RF-ST cooking (84 min). For the ST cooking, the probe position with the lowest calculated P_{70}^{10} value was at P2, as expected in conventional heating. In contrast, the RF-ST cooking showed the lowest P_{70}^{10} at P3, which was the lowest P_{70}^{10} observed in both treatments. Therefore, the ST cooking applied after RF was not long enough to compensate for the low temperature at the outer areas of the ham just after the RF cooking step (**Fig. 5**) and similar P_{70}^{10} values to those of conventional cooking were not achieved. On the contrary, the P_{70}^{10} values of RF-ST hams in the core were higher than those of ST hams (P_{70}^{10}= 70 min vs. 50 min).

In Zhang, Lyng, & Brunton (2004, 2006) the lethality values were much lower for RF cooked samples than for conventionally cooked samples. Zhang, Lyng, & Brunton (2004) suggested extending the holding time after the RF treatment as a possible solution to this problem. Schlisselberg et al. (2013) improved lethality values of RF cooking by combining both RF and conventional cooking in an oven.

The results obtained for the RF-ST process indicate that the final ST cooking step should be extended to obtain a P_{70}^{10} value, at position P3, equivalent to that at P2. In **Fig. 6b**, the P-2cm-surface accumulated lethality plot is projected beyond 180 min (grey dashed line) to estimate the additional heating process needed to obtain an accumulated lethality equivalent to the reference value in the core of the ST hams (P_{70}^{10} = 50). According to these calculations, 30 more min are needed. Another solution could be to shorten the RF cooking and to extend the ST cooking. Thus, the final temperature and P_{70}^{10} values in P1 and P3 would decrease after RF cooking and the P_{70}^{10} values in P2 would increase after ST cooking, achieving a more uniform cooking of the product.

3.4. Physicochemical characteristics and cooking yield

The uncooked (raw) ham composition (mean ±sd) was (g/100 g): 74.8 ±0.5 moisture, 16.9 ±0.1 protein, 4.8 ±0.6 fat and 2.2 ±0.1 NaCl. Significant differences between raw and cooked products were only observed in protein, moisture contents and pH values. A slightly higher protein content ($P<0.05$) was observed in the ST (17.7 ±0.3 g/100 g) and in the RF-ST (17.5 ±0.3 g/100 g) in comparison with the raw product due to the cooking losses. In relation with this, moisture content was slightly lower in the ST (73.9 ±0.7 g/100 g, $P<0.05$) and RF-ST (74.3 ±0.2 g/100 g, $P>0.05$) than in the raw product. The average pH of the raw product was 6.33 (±0.05) and increased significantly ($P<0.05$) up to 6.43 (±0.03) in both ST and RF-ST products. No significant differences ($P>0.05$) were observed in the chemical composition and pH values between ST and

RF-ST hams. Regarding cooking yield, the RF-ST hams showed slightly lower cooking loss (*P*<0.05) than ST hams (RF-ST: 2.9% vs. ST: 4.8 %), which can be explained by the differences in the total cooking time. Usually, the faster the cooking, the lower the cooking losses (Lawrie, 2006). Previous studies comparing RF cooking and steam/water bath cooking of meat products were not conclusive on differences in cooking yields.

3.5. Sensory analysis

During descriptors generation, no differences in visual colour were observed between ST and RF-ST hams (**Fig. 7**). Therefore, no appearance attributes were included in the sensory profile. **Table 1** shows the results of the effect of the cooking process (ST vs. RF-ST) on the sensory attributes of cooked ham. Slight significant differences (*P*<0.05) between cooking processes were detected only in odour (overall intensity and cooked odour) and in hardness and elasticity of the external part of the slices. ST hams were rated with higher intensity of odour and lower hardness and elasticity than RF-ST hams.

Results of previous studies were not conclusive. The studies of Zhang, Lyng, & Brunton (2004) in pork luncheon rolls and Zhang, Lyng, & Brunton (2006) in cooked leg and shoulder hams, reported that panellists were able to discriminate between RF and steam cooked meat products in similarity tests and RF cooked meat products were significantly firmer than their steam cooked counterparts. In contrast, Brunton et al. (2005) in white pudding and Tang, Lyng, Cronin, & Durand (2006) in beef rolls reported no significant differences in sensory analysis of RF and steam cooked meat products. These discrepancies could be related to the different combinations of time and temperature applied in each study.

Heat treatment induces modifications of the meat structure and its constituents (Davis & Williams, 1998). Denaturation, aggregation and degradation of myofibrillar, sarcoplasmic and connective tissue proteins occur depending on the combination of time and temperature during the heat treatment (Dominguez-Hernández, Salaseviciene, & Ertbjerg, 2018). The rate and extent of the changes are dependent on the amount of heat transferred to the meat, and on the heating rate (Tornberg, 2005). Cooked ham odour and flavour are the result of complex interactions between precursors derived from both lean and fat that generate volatile compounds that contribute to their final aroma throughout the fatty acid oxidation releasing aldehydes, alcohols, ketones and medium chain fatty acids which can react with Maillard reaction and thiamine degradation compounds (Thomas, Mercier, Tournayre, Martin, & Berdague, 2013). Ames, Guy & Kipping (2001) concluded that the amounts of most volatile flavour compounds increased during cooking.

In the present study, the slight differences in flavour and texture between ST and RF-ST hams could be related to the fact that the external part of the ST hams was subjected to high temperatures (72 °C) for a longer time than in RF-ST hams. The lower hardness and elasticity values in ST hams could also be due to the longer cooking process that helps to solubilize connective tissue.

4. Conclusion

The combination of radio frequency and steam cooking (RF-ST process) allowed obtaining a cooked pork ham similar to that obtained with conventional steam cooking (ST). The RF-ST process time was reduced by 50%. Slight differences were observed in the technological and sensory quality of the final product. Regarding the food safety of the RF-ST process, the lethality values could be further improved by adjusting the times of both RF and steam cooking. In order to avoid overheating problems in the product during the RF process, the ends of the hams should be shielded with aluminium foil or a similar material.

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Fig. 1. RF 15 KW STALAM Radio Frequency system at 27.12 MHz (STALAM S.p.A., Italy; www.stalam.com) at IRTA facilities in Monells.

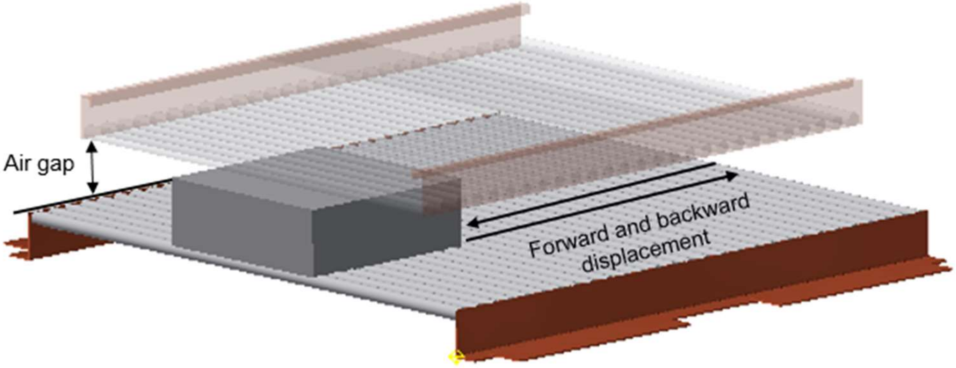


Fig. 2. Sketch of the staggered through-field electrode applicator showing the cavity with the container (with the ham and distilled water) during the RF cooking process.

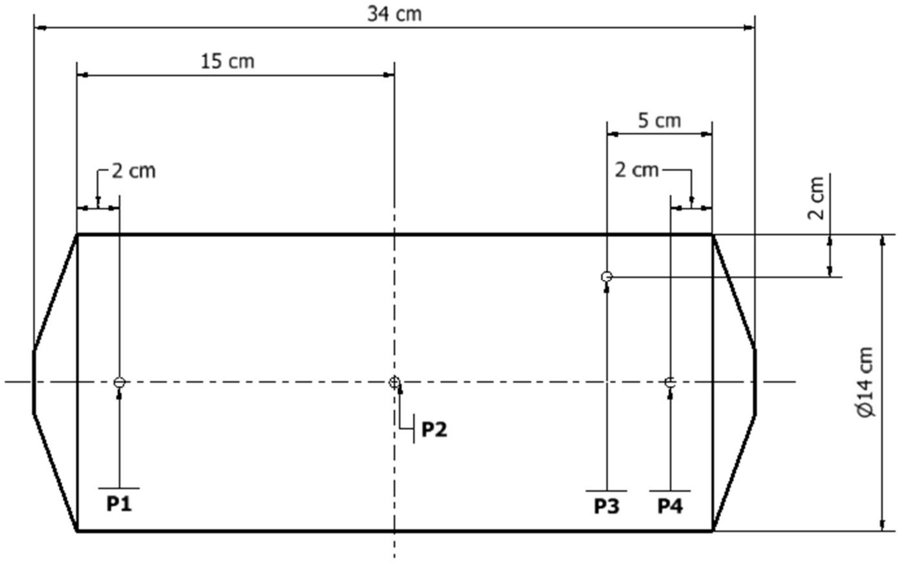
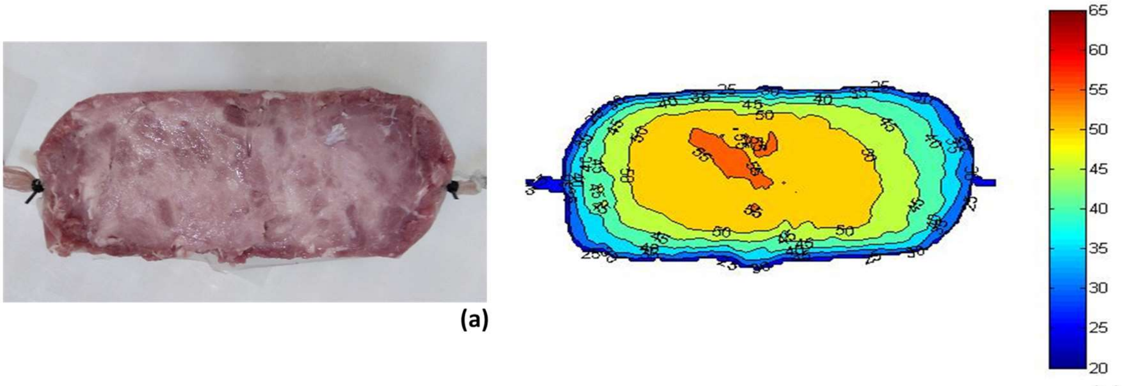


Fig. 3. Sketch of the axial section of a ham showing the positions (P1 - P4) and the penetration depth of the temperature probes (optic fibre and thermocouples) inserted in the product to monitor and record the temperature during the cooking processes. Two optic probes inserted at positions P2 and P1 or P4 were used to monitor the temperature during RF cooking. Four thermocouples inserted at positions P1 to P4 were used during ST cooking.

Fig. 4. Uncooked pork shoulder ham with aluminium foil shielding at the ends and with the two optic fibre probes inserted at the core (P2) and at the end of the ham (left side; P1 or P4; **Fig. 3**) to measure the temperature during RF cooking.



(a)

(b)

Fig. 5. Cooked ham cut after finishing the RF cooking process (with aluminium foil shielding at the ends; see Fig. 4). **a**) Axial cross-section showing the uncooked outer layer (darker area) and the inner cooked zone (pale-pink area). **b**) Thermographic image of the axial cross-section.

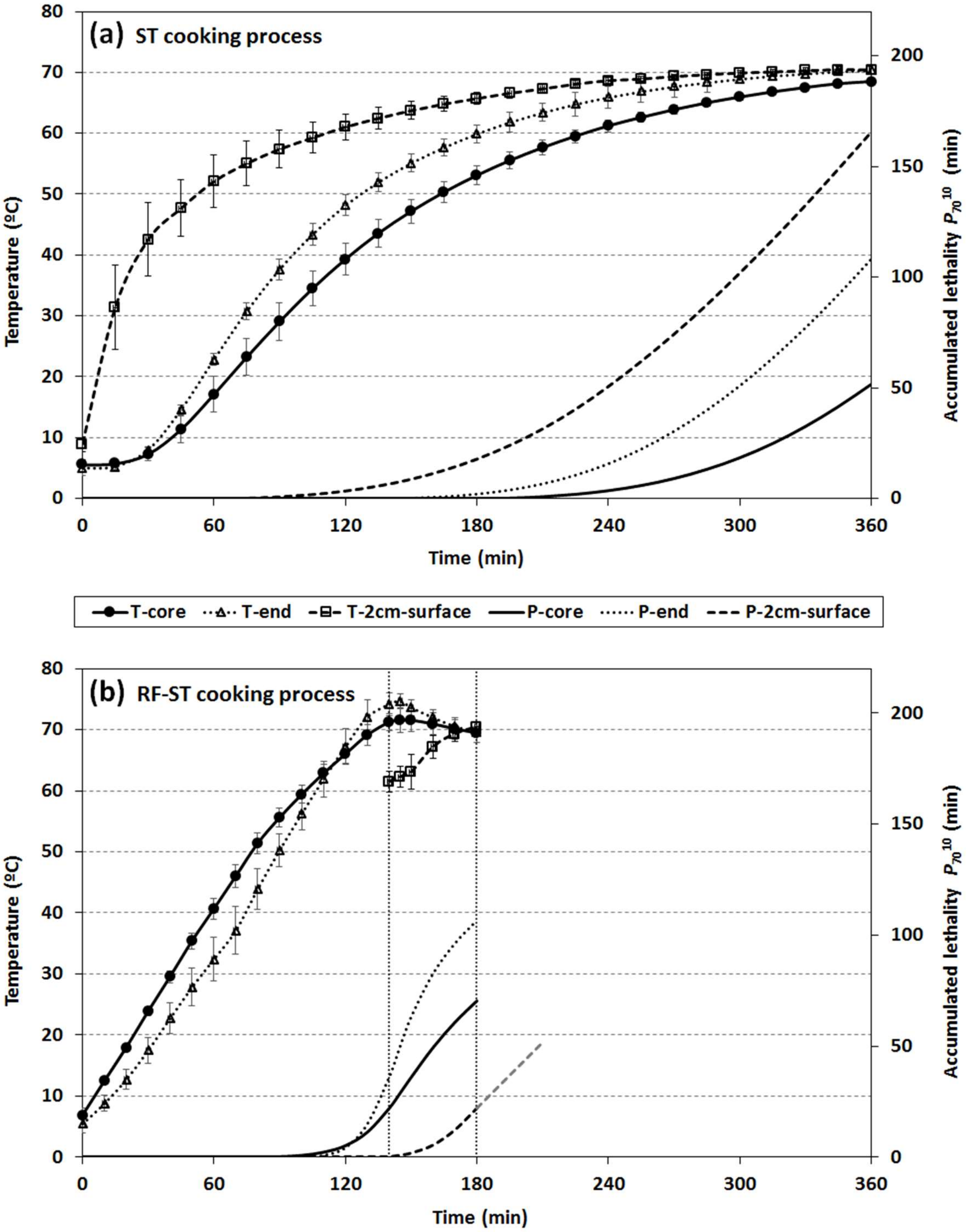


Fig. 6. Time vs. temperature and time vs. accumulated lethality $\boldsymbol{P}_{70}^{10}$ profiles for conventional steam (ST; **Fig. 6a**) and radio frequency plus steam (RF-ST; **Fig. 6b**) cooking processes. Temperature and accumulated lethality correspond to ham positions P2: core (○), P1 and P4: end (**Δ**, mean of the two probes per ham) and P3: 2 cm below the surface (□), as shown in **Fig. 3**. The plotted temperature data are mean values (± standard deviation) of ST (n= 7 hams) and RF-ST (n= 4 hams) cooking processes. In **Fig. 6b** (RF-ST) the vertical dotted lines mark the end (t= 140 min) of the RF cooking and the end (t= 180 min) of the final steam cooking. The surface accumulated lethality plot (P-2cm-surface, **Fig. 6b**) is projected beyond 180 min (grey dashed

line) to show an estimation of the additional heating process needed to obtain an accumulated lethality equivalent to the reference value in the core of the ST hams ($\boldsymbol{P}_{70}^{10}$ = 50, **Fig. 6a**).

Fig. 7. Cooked ham slices of ST (conventional steam cooking) and RF-ST (RF plus final steam cooking) processes.

Table 1. Effect of the cooking process: conventional steam cooking (ST) and radio frequency plus final steam cooking (RF-ST) on the sensory attributes of cooked pork shoulder ham.

Sensory attributes [A]	ST	RF-ST	Significance [B]	RMSE [C]
Odour				
Overall intensity	5.4	4.9	*	0.29
Cooked	5.1	4.6	*	0.28
Taste/flavour				
Intensity	5.8	5.9	NS	0.19
Saltiness	4.9	5.0	NS	0.11
Sweetness	2.0	1.9	NS	0.11
Texture (slice outer part)				
Hardness	5.1	5.5	*	0.17
Elasticity	4.9	5.1	*	0.14
Cohesiveness	4.9	5.0	NS	0.16
Juiciness	5.7	5.6	NS	0.22
Texture (slice inner part)				
Hardness	5.3	5.3	NS	0.12
Elasticity	4.8	4.8	NS	0.19
Cohesiveness	5.3	5.3	NS	0.09
Juiciness	6.1	6.1	NS	0.08

[A] Non-structured scoring scale (0= absence and 10=highest intensity of the descriptor).

[B] Significance: NS, non-significant; *, P<0.05.

[C] RMSE: root mean square error of the model.

Conflict of Interest Form

- The manuscript titled “Radio frequency cooking in distilled-water immersion of large-calibre pork shoulder hams with a final conventional steam cooking”, submitted to LWT – Food Science and Technology Journal, has not been submitted to, nor is under review at, another journal or other publishing venue.

- The authors (Israel Muñoz, Xavier Serra, M. Dolors Guàrdia, Dinar Fartdinov, Jacint Arnau, Pierre A. Picouet and Pere Gou) have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript