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Simulation of the industrial-scale heating treatment of Canadian-style smoked pork loin

Aline Fernanda CAMPAGNARO[1*], Ana Leticia BACK[2], Evandro BONA[3], Cristiane CANAN[1,2], Deisy Alessandra DRUNKLER[1,2]

Abstract

The aim of this study was to validate and simulate the thermal processing of Canadian-style Smoked Pork Loin on an industrial scale. The cooking oven temperature was evaluated at the corners and central points, obtaining the cold spot. At this point, product temperatures were collected for lethality calculation, observing the following reductions: 14,215 cycles for *Salmonella* spp., 641 for *L. monocytogenes*, and 71 for *E. faecalis*. With the simulation of heat transfer by conduction using Fourier's law, it was verified that only 120 min of cooking was necessary to reach the internal temperature of 72 °C in the product, which would result in a reduction of 165 min in the process (a complete cycle is currently 285 min). There was no significant difference between the cooked treatments for 120 and 240 min compared to the control by the sensorial analysis. The thermal treatment carried out industrially is suitable and may be reproduced safely.

Keywords: food safety; Fourier's law; industrial scale; lethality; microorganisms.

Practical Application: The work verified that it is possible to reduce the cooking time of Canadian-style Smoked Pork Loin on an industrial scale, guaranteeing microbiological safety and sensorial quality.

1 INTRODUCTION

Failures in good manufacturing practices during food processing or storage, especially using inappropriate temperatures, may result in the development of pathogenic and spoilage microorganisms. Therefore, strict temperature control throughout the food production chain, especially for ready-to-eat foods, is necessary (Demaître et al., 2020).

Pathogenic microorganisms cause significant public health problems and may cause mild discomfort and even death. About 600 million, that is, 1 in 10 people worldwide, become ill after consuming contaminated food. Of these, 420,000 people die, including 125,000 children under 5 years (World Health Organization [WHO], 2024).

Pork-derived meat products represent a major food safety concern, especially due to their association with pathogens such as *Salmonella* spp. and *Listeria monocytogenes*. These microorganisms are among the main causes of foodborne disease outbreaks on a global scale. *Salmonella* spp. is one of the main causes of gastroenteritis worldwide, with pork-based meat products being a significant source of infection. In turn, *L. monocytogenes* is the etiological agent of listeriosis, a serious invasive disease. The ability of these microorganisms to survive and proliferate in adverse environmental conditions contributes to their persistence in various processing environments. In this context, the pork meat products sector has been particularly impacted by foodborne outbreaks, with emphasis on ready-to-eat products, which constitute the main route of transmission (Lagarde et al., 2024; Saenkankam et al., 2025).

The species *Enterococcus faecium* and *E. faecalis* are often linked to infections in animals and humans and are indicators of the efficiency of the thermal treatment, and with greater importance in pasteurized meat products, standing out throughout the swine meat chain (Rizzotti et al., 2016).

One of the leading pork cuts is the loin, characterized by its high tenderness and juiciness, used in developing several processed meat products, including ready-to-eat products. In Brazil, it is prepared in different ways according to Brazilian legislation, highlighting the Canadian-style Smoked Pork Loin, which may be defined as the cut obtained from pig carcasses (loin) in whole or partial pieces, added ingredients, embedded in natural and artificial wrappings, and submitted to the process of adequate technology, smoked or not (Brasil, 2000).

During the manufacturing steps of Canadian-style Smoked Pork Loin, the thermal process is considered one of the most critical factors for the conservation and quality assurance of the final product. Therefore, thermal properties are essential for the modeling and evaluation of food processing operations involving heat transfer. Excessive heat unnecessarily increases processing costs and may compromise the quality and safety of food (Marcotte et al., 2008).

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[1]*Universidade Tecnológica Federal do Paraná, Departamento Acadêmico de Alimentos, Programa de Pós-Graduação em Tecnologia de Alimentos, Medianeira, Paraná, Brazil.*
[2]*Universidade Tecnológica Federal do Paraná, Departamento Acadêmico de Alimentos, Curso de Graduação em Engenharia de Alimentos, Medianeira, Paraná, Brazil.*
[3]*Universidade Tecnológica Federal do Paraná, Departamento Acadêmico de Alimentos, Programa de Pós-Graduação em Tecnologia de Alimentos, Campo Mourão, Paraná, Brazil.*
*Corresponding author: alinefcampagnaro@gmail.com
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This control may be performed by validating the heat treatment, defining the target microorganism, and the most resistant to the process (Liu et al., 2018). For this validation, it is necessary to establish documented criteria ensuring the execution of procedures in a reproducible way, being carried out through the analysis of temperature and products, obtaining evidence that demonstrates that a control measure or its combinations may control the hazard with a specific result that is, it is proof that the critical limits may handle the risks identified in the crucial points (Codex Alimentarius Commission, 1999).

Using instruments associated with advanced data analysis software has been the best approach for significant changes in the predictive modeling of thermophysical properties (Paluri et al., 2018). Thermal properties are parameters for optimizing the design and systems of refrigeration, cooking, and freezing (Marcotte et al., 2008). In addition to modeling and evaluating food processing involving heat transfer, they are essential for energy costs, food quality, and safety (Pereira et al., 2013).

This work aimed to validate Canadian-style Smoked Pork Loin's thermal processing using *Enterococcus faecalis*, *Salmonella* spp., and *Listeria monocytogenes* as reference microorganisms and to simulate heat transfer in Canadian-style Smoked Pork Loin to optimize the time/temperature binomial of the thermal process on an industrial scale, contributing to innovation in food safety and processing efficiency.

1.1 Relevance of the work

This study is relevant because it demonstrates the possibility of significantly reducing the cooking time of Canadian-style smoked pork loin on an industrial scale, while maintaining the microbiological safety and sensory quality of the product. The application of mathematical simulation and thermal validation contributes to optimizing processes, reducing production costs, and increasing energy efficiency. Furthermore, the work offers scientific and technological support to the meat industry, strengthening food safety and promoting innovation in ready-to-eat products.

2 MATERIAL AND METHODS

2.1 Canadian-style smoked pork loin production

The Canadian-style smoked pork loin was produced in a medium-sized slaughterhouse located in the western region of Paraná, Brazil. The loin was obtained from the slaughtering sector of the establishment itself. After deboning and cleaning, the cut was sent to the industrialization sector, where it was weighed, crushed on a disc with 18 mm diameter, added the formulation ingredients (salt, curing salts, condiments, and seasonings), within the legislation for this product (Brasil, 2000), remained mixing in a stainless steel tank automatically for approximately 45 min, afterward, the mass produced was transferred to stainless steel carts with capacity for 250–300kg, and destined for the pasta curing chamber at temperature between 5 and 10 °C where they remained at rest for a minimum of 4 h. After that, it was stuffed in wrappings 78-gauge (fibrous casing packaging), 26 or 12 cm long and 7 cm wide (diameter), and directed to the smoker, where the liquid smoke was sprayed onto the product and, subsequently, led to the cooking process, where the study was carried out. After cooking, the product was cooled and sent to the primary packaging, with a 0.6–1.0kg capacity, and secondary packaging, with a total of 12kg. They were stored at a maximum temperature of 8 °C.

2.2 Oven heat distribution study

A cooking oven (Model EMI 10 CP VPI, INCOMAF, Rio Grande do Sul, Brazil) with forced air ventilation and dry cooking (5.8 m long, 2.27 m high, and 2.85 m wide) was used. Each oven may accommodate 10 stainless steel trays, allocated in pairs (side by side), with a maximum load of 4000kg. The temperature profiles inside the oven were measured using a PT100 sensor (NOVUS, Fieldlogger, Porto Alegre, RS, Brazil) with a working range from −50 °C to +200 °C (previously calibrated), 0.1 °C resolution, and data were collected every 2 min, according to the methodology described by Santos Filho and Penna (2003) with adaptations. The sensors were allocated at 12 different points in the oven, fixed on the wall, and not in contact with its surface during the heat distribution studies. They were allocated at the ends of the stainless-steel trays, at the door, middle, and bottom points. The readings for cold spot evaluation were performed in the oven (full) in duplicate for batches with similar characteristics at maximum capacity and evaluated according to the internal oven time and temperature schedule (60 °C/30 min; 65 °C/45 min; 70 °C/60 min; 72 °C/30 min; 75 °C/60 min; and 80 °C/60 min).

Heat Penetration Study in the Loading Unit was conducted Once the cold spot was determined (the spot with the lowest temperature inside the oven), and the pork loins were oven-cooked in two batches with the same characteristics, where the lowest heat distribution value was obtained (oven's cold spot) as per the program (2.2). For thermal process data collection, a sensor with a working range from −50 °C to +200 °C (previously calibrated), 0.1 °C resolution, with data collection every 2 min, and a PT100 suitable to reach the part's geometric center was used. The process was performed in duplicate. The internal temperature data were used to calculate the cooking lethality.

2.3 Cooking stage thermal validation with the bigelow model

The Bigelow model was used to describe the dependence of the parameters on temperature (Miller et al., 2009) and the data obtained from the literature (Bugiereck et al., 2015; Feiner, 2006; Stumbo, 1973).

$$L = 10^{(T-Tr)/Z} \tag{1}$$

The lethal rate (L) was calculated in each temperature range evaluated using Equation 1. In the end, the values were added to obtain the total lethal rate and multiplied by time variation (Equation 2), divided by the tabulated D value (Equation 3), which shows the number of cycles reduced:

$$FTr = (L_1 + L_2 + L_3 + \cdots + L_{n-1})\Delta t \quad (2)$$

$$Number\ of\ reduction = \frac{FTr}{D} \quad (3)$$

where z (°C) is the number of degrees Celsius required to modify the D value (decimal reduction time) by a factor of ten; Dref (min) is the D value at Tref (reference temperature); L is the thermal process lethality index or lethal value, FTr is the F value or death period, and Δt is the time interval between two successive temperature measurements.

2.4 Heat transfer simulation in Canadian-style smoked pork loin

Heat transfer by conduction in Canadian-style Smoked Pork Loin was modeled using the Fourier equation (Equation 4):

$$\frac{\partial T}{\partial t} = \kappa \nabla^2 T \quad (4)$$

where T is the temperature (K), t is the time (s), and κ is the effective thermal conductivity (W m^{-1} K^{-1}).

Canadian-style Smoked Pork Loin was evaluated in two sizes of pieces: large (26 cm long x 7 cm in diameter) and small (12 cm long x 7 cm in diameter). According to the geometry and dimensions of the product, the simulation domain was considered an infinite solid cylinder. Only the radial contribution was considered in the heat transfer process, and Equation 4 may be simplified to Equation 5:

$$\frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\kappa \frac{\partial T}{\partial r}\right) \quad (5)$$

where r is the radius (m). As an initial condition, the temperature of the loins before cooking was adopted for the entire domain (Equation 6).

$$T = T_i \qquad 0 < r < a \qquad t = 0 \quad (6)$$

where T_i is the loin's initial temperature (K) and a is the radius (m) of the simulated loins. In the boundaries, the Dirichlet condition was adopted (Equation 7):

$$T = T_s \qquad r = a \qquad t \geq 0 \quad (7)$$

where T_s is the temperature (K) on the surface of the Canadian-style Smoked Pork Loin. The temperature on the surface was considered equal to the temperature recorded on a thermometer installed in the oven in a region close to the pork loins that had the temperature monitored (Point 11 - the cold spot of the oven). The condition expressed in Equation 7 is valid when the Biot number is infinite (Bi > 100 in real applications) and the thermal equilibrium is reached (Zheleva & Kamburova, 2009). The Biot number is the ratio of internal and external resistance; considering that the oven has forced air ventilation, the external resistance is lower than the internal resistance, so the Biot number could be considered higher than 100, and the Dirichlet boundary condition is valid. The forced air circulation also guarantees the thermal equilibrium on the loin surface. Another critical point is the package involving the loin; in the present study, the package thickness is less than 1 mm, so the simulation ignored this effect due to the low thickness of the package.

From Equation 5, considering the initial condition (6) and boundary condition (7), the solution to the heat transfer problem by conduction was obtained through Equation (8), developed by Carslaw and Jaeger (1959) and also presented by Crank (1975) for mass transfer by diffusion:

$$\frac{T - T_i}{T_s - T_i} = 1 - \frac{2}{a}\sum_{n=1}^{\infty} \frac{exp\,(-\kappa\alpha_n^2 t) J_0(r\alpha_n)}{\alpha_n J_1(a\alpha_n)} \quad (8)$$

In Equation 8, $J_0(x)$ and $J_1(x)$ are Bessel functions of the first type of zero-order and first-order, respectively. Already α_n are the positive roots of Equation 9:

$$J_0(a\alpha_n) = 0 \quad (9)$$

For the simulation of heat transfer by conduction in Canadian-style Smoked Pork Loin, a routine was developed to apply Equation 8 in MATLAB R2022b software. In all simulations, the series was truncated after the tenth term ($n = 10$). The percentage deviation of the observed values from the simulated values was calculated using Equation 10:

$$\%\ deviation = \frac{100}{N}\sqrt{\sum_{i=1}^{N} \left(\frac{T_{simul}^i - T_{obs}^i}{T_{obs}^i}\right)^2} \quad (10)$$

where T_{obs}^i is the temperature measured at the geometric center of the Canadian-style Smoked Pork Loin, T_{simul}^i is the simulated temperature for that same point, and N is the total number of measured temperatures.

The value of the effective coefficient of thermal conductivity (κ) was adjusted to obtain the lowest percentage deviation between observed and simulated data. After determining the effective thermal conductivity value, radial temperature distribution profiles were simulated for different cooking times. The average loin temperature for each cooking time was also calculated using Equation 11. The integral of Equation 11 was approximated using a trapezoidal rule. With the average temperature graph, it was possible to establish the time required for the loin to reach a specific temperature:

$$T_{média} = \frac{\int_0^a T_{simul}(r)\, dr}{a} \quad (11)$$

2.5 Effect of temperature on sensorial perception

Three treatments of the Canadian-style Smoked Pork Loin were prepared according to Section 2.1, differing in terms of the time taken to reach an internal temperature of 72 °C and called Control Treatment: 285 min, Treatment 1 (T1): 200 min, and Treatment 2 (T2): 120 min. The treatments were stored in sterile bags in a cold chamber at 10 °C until analysis. Sensory evaluation was performed in the individual cabin, with white light, with the participation of 100 untrained panelists (60% male and 40% female). Panelists randomly received slices of about 20g of each of the three samples (approximately 5 °C) in plastic dishes coded with random three-digit numbers, and a glass of mineral water to clean the palate between samples. Sensory evaluation was carried out using a nine-point Hedonic Scale to evaluate the attribute's appearance, aroma, color, flavor, texture, and overall impression (Instituto Adolf Lutz [IAL], 2008). The study was submitted and approved by the Ethics Committee for Research Involving Human Beings at the Medianeira Campus of the Federal Technological University of Paraná—UTFPR (CAAE 56532722.4.0000.0165).

2.6 Experimental design and statistical analysis

The temperature data collected in the ovens from the heat penetration study and sensory analysis were submitted to analysis of variance (ANOVA), and when statistical differences at a 5% significance level were detected, the Tukey test was used (Statistica 7.0 software, Statsoft Inc., Tulsa, OK). Monitoring the cooking temperature of the Canadian-style Smoked Pork Loin product was used for lethality calculations according to the *Bigelow* model (Miller et al., 2009). The MATLAB R2022b software was used for heat transfer modeling.

3 RESULTS AND DISCUSSION

By monitoring the oven temperature, it was verified that side, height, and depth, as well as the side*depth interaction ($p < .05$), interfered with heat distribution (Table 1). No significant tertiary order interactions occurred ($p > .05$). The maximum difference between the oven's hottest and coldest spots was 6.94 °C.

Table 1. Average temperatures of the different points of the cooking oven used in the preparation of the Canadian-style smoked pork loin.

Point	Side	Height	Depth	Average Temperature
11	Left	Under	Middle	69.32[a*]
4	Right	Under	Door	69.37[a]
12	Left	Under	Ground	69.57[ab]
10	Left	Under	Door	70.16[abc]
5	Right	Under	Middle	70.22[abc]
8	Left	Upper	Middle	72.62[bcd]
6	Right	Under	Ground	72.89[cd]
9	Left	Upper	Ground	73.74[de]
2	Right	Upper	Middle	74.05[de]
7	Left	Upper	Door	74.06[de]
1	Right	Upper	Door	74.24[de]
3	Right	Upper	Ground	76.26[e]

*Means followed by lowercase letters do not differ from each other at the 5% probability level.

Among the analyzed parameters, the most relevant was height ($p < .00$). All points in the "lower" height had lower temperatures except the lower right bottom end. The hot air in the greenhouse is blown in through the top of the equipment and distributed along the walls; therefore, the upper height presented the highest temperature values, occurring for both sides of the equipment, with the value found with the highest temperature at Point 3 (bottom depth). Therefore, it may be concluded that deep, that the lowest values are located at the central points, followed by the doors, and finally, the bottom, due to air circulation in the equipment.

The left one obtained the lowest values for the side, and a difference in side-depth interaction was observed ($p < .05$). It is worth noting that the heat distribution inside the equipment was relatively homogeneous due to a temperature difference of up to 7 °C among the points.

Points 11, 4, 12, 10, and 5 did not differ significantly from each other ($p < .05$) and presented the lowest temperature values among the points evaluated. However, the chosen point (since only one could be elected) was the one that showed the lowest average temperature among the treatments that stayed the same (Point 11: left, bottom, and middle). It is important to emphasize that the cold spot study should be carried out for each product and industrial process, since various factors may interfere with its selection. Brustolin (2017) found that the cold spot in the oven used to cook Mortadella was at the trays' door ($R^2 > .960$).

For lethality calculation, it is known that the heat treatments should produce the desired logarithmic reduction of the target microorganism, thus reaching the desired safety (Codex Alimentarius Commission, 1999). There is no specific legislation for Canadian-style Smoked Pork Loin regarding the number of logarithmic cycle reductions or target microorganisms. Food Safety and Inspection Service (FSIS), Cooking Guideline for Meat and Poultry Products (United States Department of Agriculture [USDA], 2017) is widely used by the meat and poultry industries to establish pathogen reduction requirements described in thermal processes. However, according to Brazilian legislation (Brasil, 2015), there is a need to reduce six log cycles for the Mortadella product, the only one having nationwide covering legislation, with *Streptococcus D* as the target microorganism. The existing literature recommends 5–10 log cycle reductions for pasteurized products (Brasil, 2015; Reichert, 1988; Stumbo, 1973).

The results for the lethality calculation at the coldest spot (Point 11) indicated that the heat treatment with varying times and temperatures, which recommends a minimum 72 °C temperature at the product's geometric center, was efficient and ensured the microbiological safety of the products for the target microorganisms (Table 2).

Few studies on this topic are found in the literature, even more so for the product under investigation. However, in this study, the result for *E. faecalis* (Table 2) was higher than that achieved by Brustolin (2017), who obtained an eight-cycle logarithmic reduction for *Streptococcus D* for Mortadella, higher than recommended by the Brazilian legislation (six cycles) (Brasil, 2015).

The results for *Salmonella* spp. and *L. monocytogenes* (Table 2) showed that the reduction cycles were higher than the limit set by Feiner (2006), Stumbo (1973), and the USDA (2017), which state six-cycle reductions.

Table 3 shows that Canadian-style Smoked Pork Loin obtained an average effective thermal conductivity coefficient of 0.623 ± 0.032 W m^{-1} K^{-1}, taking all simulations into account. The κ value presented slight variations in the four simulations performed. This result is expected since the effective thermal conductivity depends on the simulated material's thermal properties, not the heat transfer process conditions.

The values found are similar to the ones for meat products listed in the literature. Tadini et al. (2017) obtained 0.43 W m^{-1} K^{-1} at 39 °C and 0.51 W m^{-1} K^{-1} at 67 °C values for beef. (Torres et al., 2020) found a 0.4996 W m^{-1} K^{-1} value for meat. When studying the Calabrian-style sausage, Bugiereck et al. (2015) found values around 0.42 W m^{-1} K^{-1}. Pereira et al. (2013) found values ranging from 0.1 to 5.0 W m^{-1} K^{-1} for chicken, with chicken breast presenting the lowest value at low humidity (33%). In contrast, chicken breasts, drumsticks, and thighs gave the highest value at a higher humidity level (70%). Poultry skin and fat obtained values ranging from 0.31 to 0.39 W m^{-1} K^{-1}.

The simulated and experimental temperatures at the Canadian-style Smoked Pork Loin geometric center presented a good agreement. Figure 1A shows the simulated temperature variation along the radial dimension of the Canadian-style Smoked Pork Loin. At the beginning of the cooking process, the pork loin's center and surface presented a more significant temperature difference. A temperature ranging between 70 °C and 80 °C was reached at all points of the pork loin after 180 min. The 72 °C temperature is achieved after 120 min of cooking, as seen in Figure 1B.

Marcotte et al. (2008) evaluated the thermophysical properties (heat transfer, thermal conductivity, and diffusivity) of Mortadella, Wiener, Pepperoni, Turkey emulsion, and Flaked Ham using a temperature range from 20 °C to 80 °C. They found good agreement among all these properties.

Bugiereck et al. (2015) optimized the thermal processing conditions for Calabrian-Style Sausage, decreasing it from 320 to 316 min, resulting in 40 extra batches daily. According to the lethality calculations presented in this study, the product's internal temperature kept at 70 °C for 3 min may be enough to eliminate the target microorganisms. Therefore, proper microbiological conditions could contribute to reducing cooking time—120 min is enough to reach 72 °C—and produce the same effect as the complete 285-min heat treatment cycle, optimizing the process.

However, the heat treatment is also responsible for the sensory characteristics of the final product (color, flavor, and texture) (Silva & Gibbs, 2012). The samples were submitted for microbiological analysis to guarantee their safety for the sensorial analysis. According to the results obtained, all treatments were by current legislation; therefore, they could perform the sensory analysis (Brasil, 2019).

The panelists were 60% male and 40% female. As expected, the predominant age group was 18–25 years old, and incomplete higher school education, since the group of tasters was primarily composed of university students. For the question related to family income, most are in the range of US$ 250–1000. When the tasters were asked about pork derivatives, the majority stated that they consume them at least one to three times a week. In turn, regarding Canadian-Style Smoked Pork Loin, the frequency of consumption was low, even though it is among the cold cuts most used in producing ready meals, such as pizzas and snacks. Among those who consume the product,

Table 2. Calculation of lethality in the cooking process of the Canadian-style smoked pork loin for the target microorganisms.

Microorganism	Number of required reductions	F required (min)	Lethal rate	Total F calculated (min)	Number of calculated reductions (F/D)
*E. faecalis**	6 D	18	106.5	213.1	71
*Salmonella spp.***	12 D	2	1222	2445	14.215
*L. monocytogenes****	6 D	10	535	1070	641

*Parameters: D = 3 min, z = 10 °C, reference temperature = 70 °C.
**Parameters: D = 0.172 min, z = 5.6 °C, reference temperature = 65.6 °C.
***Parameters: D = 1.67 min, z = 8 °C, reference temperature = 65 °C.

Table 3. Simulation conditions and results obtained for effective thermal conductivity at the geometric point of the Canadian-style smoked pork loin.

	1	2	3	4
Canadian-style Smoked Pork Loin	**Large (26 cm x 7 cm)**	**Small (12 cm x 7 cm)**	**Large (26 cm x 7 cm)**	**Small (12 cm x 7 cm)**
Side	Right	Right	Left	Left
a (cm)	3.5	3.5	3.5	3.5
n	10	10	10	10
κ (W m^{-1} K^{-1})	0.652	0.645	0.583	0.612
% deviation	6.09	2.60	6.74	5.28

a: ay in cm; n: number of terms in the series in Equation 8; κ: effective thermal conductivity.

88% mentioned that they do so through pizzas, sandwiches, and prepared meals in general; in the form of an aperitif/ ready-to-eat, only 12% of the tasters.

Therefore, sensory analyses are needed to verify if the product's sensory characteristics are met (Figure 2). Regarding the evaluated attributes, the treatments did not present a significant difference between them ($p > .05$).

All evaluated attributes were rated between moderately liked (7) and very much appreciated (8), demonstrating good acceptance of the products by the tasters. The heat treatment conditions used in cooking meat products significantly influence the sensory quality of meat products, such as tenderness, juiciness, color, and flavor (Rinaldi et al., 2011). Through these results, it is possible to notice that the reduction of cooking time (in treatments 1 and 2) did not result in perceptible changes from the point of view of the evaluated sensorial characteristics. It is important to note that this change in cooking time may result in significant savings for the industry, which currently works with a cooking time of 285 min.

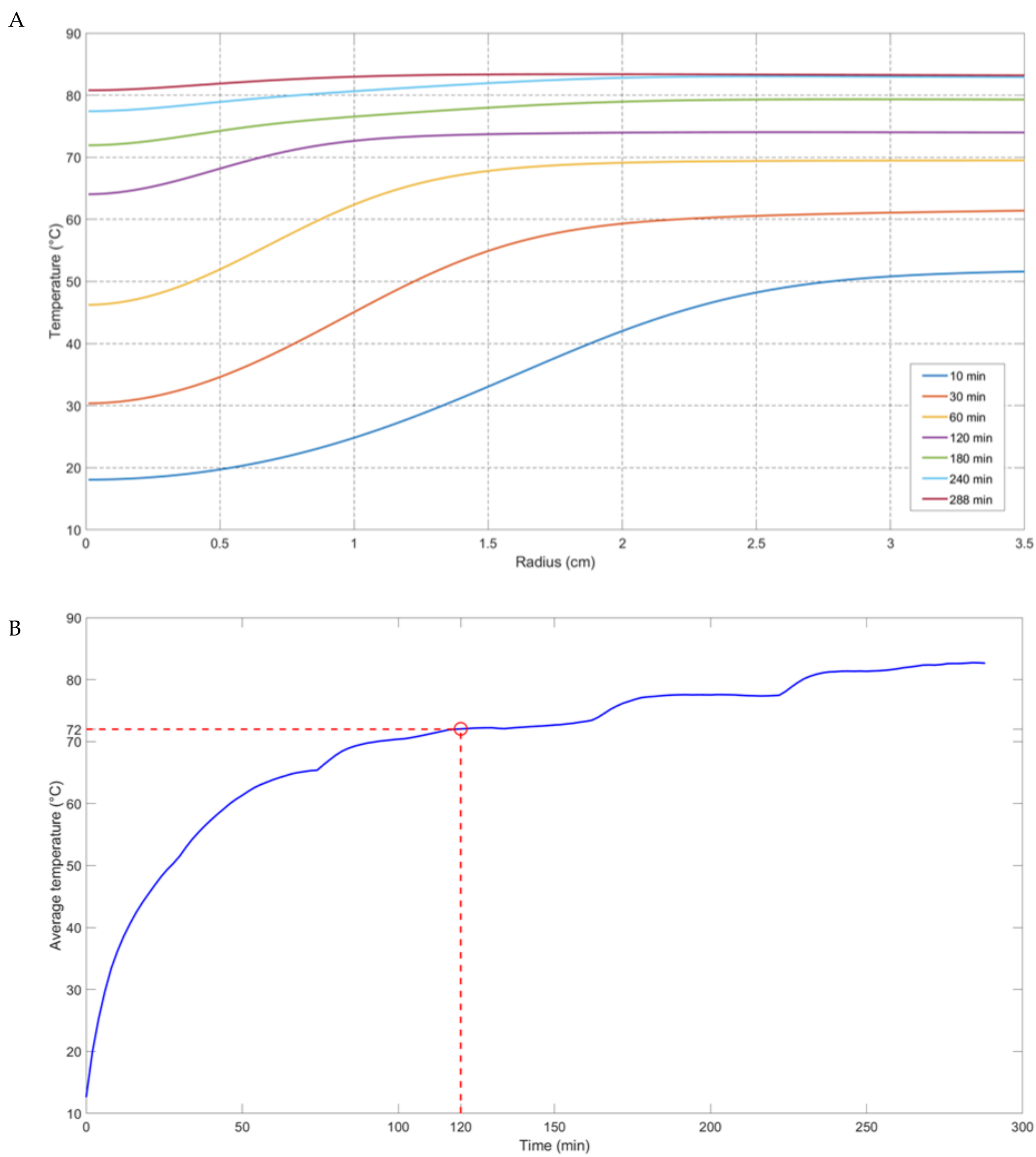

Figure 1. Temperature distribution (A) radial and (B) average temperature.

Color is the first sensory characteristic observed by the consumer when choosing meat and meat products, and it has a very powerful reference on quality, especially for smoked meat products. In turn, in the instrumental assessment of color for some attributes, the treatments differed at a 5% probability level (Table 4). However, these differences were not perceptible by the tasters (Figure 2).

When comparing the treatments, internally and externally, it is possible to verify that Treatment 2 presented the lowest values for L^* ($p < .05$). However, for the other attributes, the treatments did not differ in the inner portion of the piece. Already evaluating only the external surface, the values of a^*, b^*, and c^* were lower for Treatment 2 ($p < .05$), while the value of h^* was higher for Treatment 1. This difference between treatments can be justified by the influence of the cooking time on the formation of color in the products. Treatment 2 may not have been sufficient to form a color similar to the control treatment. However, the tasters did not report this difference detected in the instrumental color analysis (Table 4).

4 CONCLUSIONS

Through mathematical simulation for thermal transfer, it was demonstrated that it is possible to use a time of 120 min in the cooking step; therefore, with a shorter cooking time, there will be a significant reduction in costs and an increase in productivity, with no sensory changes in the product. The methodology presented in this study is simple and practical and may be applied to other foods on an industrial scale.

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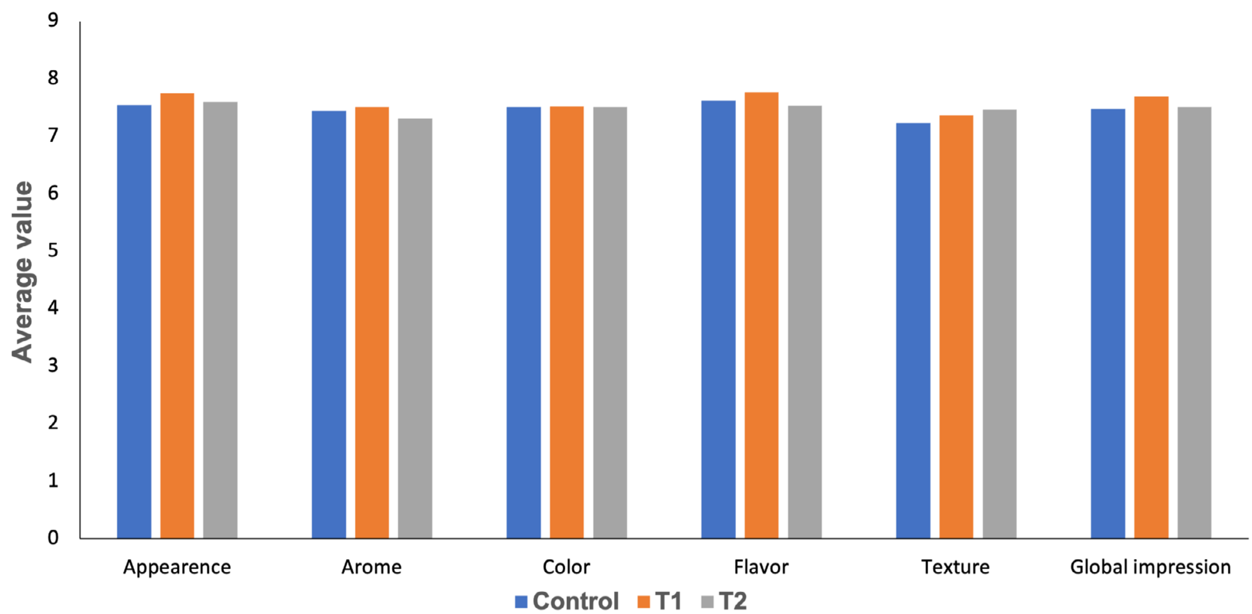

Figure 2. Sensory evaluation of commercial (Control), T1 (200 min), and T2 (120 min) pasteurized Canadian-style smoked pork loin.

Table 4. Results of the instrumental analysis of color, internal part, and external surface, of Canadian-Style smoked pork loin, with different combinations of time to reach the internal temperature of 72 °C.

Treatment**	L*	a*	b*	c*	h*
			Parts inside		
Control	$56.27 \pm 3.9^{b*}$	9.85 ± 0.8^{a}	9.68 ± 0.7^{a}	13.83 ± 0.8^{a}	44.54 ± 2.9^{a}
1	55.63 ± 3.2^{b}	9.58 ± 0.3^{a}	9.54 ± 0.8^{a}	13.53 ± 0.6^{a}	44.81 ± 2.4^{a}
2	45.66 ± 3.2^{a}	7.83 ± 1.5^{a}	7.46 ± 1.2^{a}	11.40 ± 2.2^{a}	43.66 ± 1.6^{a}
			Outer surface		
Control	44.86 ± 0.9^{c}	14.78 ± 0.6^{c}	16.59 ± 1.3^{c}	22.23 ± 1.2^{c}	48.26 ± 1.8^{a}
1	47.98 ± 0.3^{b}	17.47 ± 0.8^{b}	22.67 ± 0.8^{b}	28.62 ± 0.9^{b}	52.38 ± 1.0^{b}
2	30.58 ± 3.4^{a}	11.04 ± 2.1^{a}	12.86 ± 2.1^{a}	16.96 ± 2.9^{a}	49.44 ± 1.3^{a}

*Results are expressed as mean ± standard deviation. Different letters in the same column express a significant difference (at the 5% probability level) between treatments.**Control Treatment: 285 min of baking to reach 72 °C in the center of the piece; Treatment 1: 200 min to reach 72 °C in the center of the piece; Treatment 2: 120 min of cooking at 72 °C in the center of the piece.

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