Modeling and designing a *Listeria monocytogenes* control strategy for dry-cured ham taking advantage of water activity and storage temperature

Cristina Serra-Castelló[1], Anna Jofré[1], Margarita Garriga, Sara Bover-Cid*

IRTA. Food Safety Program. Finca Camps i Armet s/n. 17121 Monells (Spain)

Declarations of interest: none

[1]These authors contributed equally to this work.
*Corresponding author.
Tel.: +34 972 630052 extension 1488; E-mail address: sara.bovercid@irta.cat (S. Bover-Cid)

Abstract

Dry-cured ham is a shelf stable product that can be contaminated with *Listeria monocytogenes* due to post-processing operations, compromising the compliance of zero tolerance policies (e.g. US Listeria rule). The present study quantifies the behavior of *L. monocytogenes* in sliced Spanish dry-cured ham of different water activity (a_w) during storage at different temperatures. Inactivation kinetics were estimated by fitting primary models to the experimental data. The effect of temperature and a_w on kinetic parameters was characterized through secondary polynomial models. *L. monocytogenes* viability decreased in all the assayed conditions, confirming that dry-cured ham is not only listeriostatic but listericidal. The fastest and highest reductions were observed at 25 ºC, with 1 Log reduction after 6 and 9 days in Iberian and Serrano ham respectively. The work provides scientifically-based data and models to design a low-cost control measure based on a corrective storage as a post-lethality treatment to enhance the accomplishment of zero tolerance requirements.

Keywords

Listeria monocytogenes; RTE meat products; modeling; non-thermal inactivation; post-lethality treatment

1. Introduction

Dry-cured ham is a raw ready-to-eat (RTE) meat product highly appreciated worldwide for its particular sensory characteristics. In 2017, the production reached the 299,000 tonnes in Spain, more than 15% being intended for export, which represents a 70% increase of the tonnes exported in 2012 (ANICE, 2019). The traditional EU markets have been mainly France, Germany, Portugal, Italy and the United Kingdom. Major emerging markets like Mexico, USA, Australia, South Korea, Chile, Japan, Argentina and New Zealand are foreseen of a great importance for the Spanish meat sector (ANICE, 2019). Dry-cured ham is considered a shelf-stable RTE product due to its low water activity (a_w) resulting from the salting and drying process of manufacture that renders a product with a high salt content up to 15% of the dry matter (Costa-Corredor, Serra, Arnau, & Gou, 2009; FSIS, 2010). Besides, the manufacturing process of dry-cured ham includes several steps, such as salting, post-salting, curing and drying/aging, with a duration depending on the type of dry-cured ham (from 7 months in the case of Serrano type, up to 18 to 48 month for Iberian type). The processing conditions have been proved to be lethal for *Listeria monocytogenes*, reducing the levels of the pathogen when inoculated in meat raw material by 4 Log units (Reynolds, Harrison, Rose-Morrow, & Lyon, 2001) in US type of dry-cured ham to 6 Log units in Spanish type dry-cured ham (Medina, 2017).

However, it has also been demonstrated that when marketed as convenient packaged formats (e.g. boneless blocks, diced, sliced), post-processing manipulation exposes the product to cross-contamination with pathogens, *L. monocytogenes* being of particular concern due to its ubiquitous nature and persistence in processing areas (Martín, Perich, Gómez, Yangüela, Rodríguez, Garriga, et al., 2014; Talon, Lebert, Lebert, Leroy, Garriga, Aymerich, et al., 2007). The contamination during post-processing operations is highly dependent on the production plant, with a prevalence reported between 3.6% and 18.4% (Prencipe, Rizzi, Acciari, Iannetti, Giovannini, Serraino, et al., 2012). The overall occurrence of *L. monocytogenes* in retail dry-cured ham varies from not detected (Cabedo, Picart-Barrot, & Teixidó-Canelles, 2008; Giovannini, Migliorati, Prencipe, Calderone, Zuccolo, & Cozzolino, 2007) to a prevalence of *ca.* 2% (Jemmi, Pak, & Salman, 2002; Prencipe, et al., 2012), 4% (Giovannini, Migliorati, Prencipe, Calderone, Zuccolo, & Cozzolino, 2007) and up to 12% (Uyttendaele, De Troy, & Debevere, 1999).

Food safety criteria regulations regarding *L. monocytogenes* in RTE products differ between countries. For EU member states, Regulation (EC) 2073/2005 establishes a maximum of 100 CFU/g of *L. monocytogenes* during the shelf-life of the product provided it is not intended for infants or special medical purposes or it does not favor the growth of the pathogen to more than 100 CFU/g at the end of shelf-life . This regulation states that RTE foods with a_w equal or below

0.92 automatically are considered to belong to the category of RTE food unable to support the growth of *L. monocytogenes* (European Commission, 2005). This a_w value is usually used by manufacturers as the acceptable limit for the commercial production of dry-cured ham. A similar tolerance approach is applied by Canadian regulation (Health Canada, 2011) and that of Australia and New Zealand (Australian Government, 2017). In contrast, in the US *Listeria* rule (FSIS, 2015), a zero-tolerance policy is imposed, which means that RTE products must not be released if they contain *L. monocytogenes* or have been in contact with a food contact surface contaminated with the pathogen. To meet this requirement, the establishment producing RTE foods exposed to *L. monocytogenes* contamination can apply control alternatives, based on antimicrobial agents or processes (AMA/P) to suppress pathogen growth and/or post-lethality treatments (PLT) to eliminate or reduce *L. monocytogenes* (FSIS, 2015).

Although, to the authors knowledge, no listeriosis case or outbreak has been associated with dry-cured ham, the pressure derived from zero-tolerance policies of the public health authorities of some countries as well as commercial demands, poses a challenge for the dry-cured meat industry due to the technical difficulties for the control and eradication of *L. monocytogenes*. To fulfil legal and/or commercial requirements, dry-cured ham producers should design risk minimization strategies to avoid sources of recontamination and/or apply validated PLT before commercial expedition. For dry-cured ham, thermal based post-lethality treatments are not suitable due to the negative impact on the organoleptic properties. Emerging non-thermal alternatives, such as high pressure processing have been proposed, though they show limited effect due to the piezoprotection caused by the low a_w of the product (Bover-Cid, Belletti, Aymerich, & Garriga, 2015; Hereu, Bover-Cid, Garriga, & Aymerich, 2012) . Moreover, the economical investment needed to implement high pressure processing are not affordable for many producers. Therefore, feasible alternative strategies based on the physicochemical properties of the product itself should be investigated.

In this framework, the present study aimed to evaluate through a modeling approach the behavior of *L. monocytogenes* in dry-cured ham, as a function of product a_w and storage temperature. The final objective was to design a feasible control measure contributing to ensure the accomplishment of zero-tolerance policies and commercial requirements. The study was carried out in two Spanish dry-cured ham types as the most typical and appreciated by consumer, Iberian ham and Serrano ham, showing differences in raw material (Iberian vs white pigs, respectively) and the process conditions, including length (up to 600 days vs 210 days, respectively) leading to end-products with different quality and prize (Lorido et al. 2015)

2. Material and methods

2.1. *Product characteristics*

Two different types of dry-cured ham were studied: Serrano and Iberian. Three batches for each type with different weight loss (high, medium, low), corresponding to a_w values of 0.87, 0.89 and 0.91 (Serrano type) and 0.85, 0.88 and 0.91 (Iberian type) in central sections of the ham piece, were used to study the impact of different values of a_w on the *L. monocytogenes* growth. Samples of hams were obtained directly from the producer, in vacuum-packed boneless blocks format and stored under refrigeration (<2 °C) until being used. Special attention was paid to obtain sections with the target a_w, which was measured at 25 ºC using an Aqualab® equipment (Decagon Devices, Pullman, WA, USA).

2.2. L. monocytogenes *strains and inoculum preparation*

A cocktail of equal concentration of four *L. monocytogenes* strains with different genotype and serotype (Table 1), isolated from pork meat industrial environment (Medina, 2017; Ortiz, López, Villatoro, López, Carlos Davila, & Martínez-Suárez, 2010) was used . The strains were kindly provided by Dr. M. Medina (INIA, Spain). Stock cultures of each strain were kept at -80 °C in Brain Heart Infusion (BHI) broth (Beckton Dickinson, Sparks, Md., USA). A culture of each strain was separately grown in Tryptic Soy Broth with 0.6% Yeast Extract (TSBYE, Difco) following two consecutive incubation steps: firstly 18 h at 37 °C and secondly 4 days at 8 °C to obtain cold-adapted early stationary phase cultures according to the recommendations of the technical guidance document for conducting shelf-life studies on *Listeria monocytogenes* in RTE (EURL Lm, 2014). This physiological state (cold adaptation) mimics the chilled conditions usually found in clean rooms for production of RTE products (e.g. conveyor belts, slicing machines and packaging equipment).

2.3. *Challenge test: sample preparation, inoculation and storage conditions*

Boneless block hams (Serrano and Iberian, described in section 2.1) were aseptically sliced. Each slice (of *ca.* 20-30 g) was inoculated (1% v/w) with the 4-strain cocktail of *L. monocytogenes* described above to achieve *ca*. 10^6-10^7 CFU/g by properly diluting the culture in saline solution (0.85% NaCl and 0.1% Bacto Peptone (Beckton Dickinson)). The inoculum was spread on the dry-cured ham slice and left to absorb for 2 min under a laminar flow cabinet. The slices were overlaid cut in two and each part was individually vacuum packaged (in a EV-15 vacuum packer; Tecnotrip, Terrassa, Spain) in PA/PE bags (oxygen permeability of 50 $cm^3/m^2/24$ h and a low water vapor permeability of 2.8 $g/m^2/24$ h; Sistemvac, Estudi Graf S.A., Girona, Spain). Samples of each type of dry-cured ham were randomly distributed in 4 groups to be stored at 2, 8, 15 and 25 °C for a maximum of 6 months. These temperatures cover the reasonably foreseeable range for the storage and commercially display dry-cured ham, which has a maximum shelf-life of 6 months under refrigeration. The a_w value of the samples was not significantly different after the inoculation. A total of 390 samples were prepared.

2.4. *Monitoring* L. monocytogenes *behaviour*

To monitor *L. monocytogenes* survival, samples from 24 experimental conditions (2 types of dry-cured ham, 3 a_w and 4 storage temperatures) were periodically analyzed to get a total of 12 to 19 data points distributed all along the storage period. This resulted in 201 and 189 samplings for Serrano and Iberian ham, respectively. Each sample was homogenized 1/10 in saline solution in a bag Blender Smasher® (bioMérieux, Marcy-l'Etoile, France) for 1 minute and 10-fold serially diluted in saline solution. *L. monocytogenes* was enumerated on Chromogenic Listeria Agar (CLA; Oxoid Ltd., Basingstoke, Hampshire, UK) and incubated at 37 °C for 48 h. For samples with expected concentration of *L. monocytogenes* below the quantification limit of 4 CFU/g (resulting from plating 4 ml of homogenate in a 14 cm diameter plate), the presence/absence of the pathogen was investigated by enrichment of 25-30 g-samples in 225 ml of TSBYE and incubated 48 h at 37 °C. After enrichment, the presence of *L. monocytogenes* was confirmed by plating on CLA (Sara Bover-Cid, Serra-Castelló, Dalgaard, Garriga, & Jofré, 2019). For modeling purposes, samples below the detection of plate count with positive after enrichment were assumed to be 1 cell in 30 g (i.e. -1.5 Log cfu/g). Negative results (i.e. not detected in 25-30g) were not recorded in any analyzed sample.

2.5. *Primary model fitting*

Four different inactivation primary models (Table 2), including the Weibull, Log-linear, Log-linear with tail and Log-linear with shoulder models (as described in Hereu, Dalgaard, Garriga, Aymerich, Bover-Cid, 2012) were used. For modeling purposes, to avoid small differences in initial concentrations, models were fitted to the *L. monocytogenes* inactivation data, expressed in terms of Log (N/N_0) (Martino & Marks, 2007) as a function of time (days) for each of the 24 combinations of conditions (type of ham, a_w and storage temperature). In addition, the Log N/N_0 at time zero (the initial inactivation) was fixed to 0 for parsimony purposes. All primary models were fitted using R with the nls2 and nls packages of R software (R Core Team, 2019). Besides visual evaluation of the fitted curves, the standard error of the coefficients, the residual sum of squares (RSS) and the adjusted coefficient of determination (R^2_{adj}) were calculated as measures for goodness of fit. The primary model with a better goodness of fit, e.g. lower RSS and higher R^2_{adj} was chosen.

2.6. *Secondary model fitting*

Polynomial models were developed to quantitatifythe effect of the independent variables (a_w and storage temperature) on the primary kinetic parameters.. Different transformations, including square root, inverse, Ln and Log, of the primary kinetic parameters were assessed. Estimation of the model parameters was carried out with R software (R Core Team, 2019) applying stepwise backward linear regression to obtain equations with only the significant parameters. The standard error of the coefficients, RSS and R^2_{adj} were calculated as measures for goodness of fit.

Besides the two-step modeling approach described above, the global one-step regression was applied for the fine tuning of the model parameters of *L. monocytogenes* inactivation on Serrano and Iberian type hams. For this, the secondary models for δ and p were integrated into the primary Weibull model and the combined model was fitted to the entire set of inactivation data points by one-step global non-lineal regression approach (Jewell, 2012; Martino & Marks, 2007).

The goodness of fit the one-step global models were assessed in terms of standard error of the coefficients, RSS and R^2_{adj} and by using graphs of observed and fitted values. The F-test was applied to assess the need of two different models for each product type compared to the suitability of a single model for both types of dry-cured ham.

2.7. *Model predictive performance*

Inactivation data recorded for *L. monocytogenes* on dry-cured Serrano and Iberian hams collected from scientific literature (Bover-Cid, Jofré, & Garriga, 2016; Hereu, Bover-Cid, Garriga, & Aymerich, 2012; Morales, Calzada, & Nuñez, 2006) were compared with predictions obtained by the models developed in the present study. To compare the observed and predicted inactivation during storage, the Acceptable Simulation Zone (ASZ) approach was used. Simulations were considered acceptable when at least 70% of the observed Log (N/N_0) values were inside the corresponding acceptable zone, e.g ± 0.5 (Møller, Ilg, Aabo, Christensen, Dalgaard, & Hansen, 2013).

3. Results and discussion

3.1. *Description of the behavior of* L. monocytogenes *on sliced dry-cured ham*

The survival of *L. monocytogenes* under the 24 experimental conditions assayed is shown in Figure 1.The viability of *L. monocytogenes* was compromised in all the 24 conditions assayed, showing in most of the cases a significant reduction of the counts during the storage of sliced and vacuum packed dry-cured ham.

Therefore, the results indicated that under these conditions dry-cured ham is not only listeriostatic but listericidal. The magnitude of the lethal effect varied significantly according to the product characteristics and storage temperature. Thus, Iberian type ham favored an earlier and more pronounced inactivation of *L. monocytogenes*, compared with Serrano type, even if a_w was similar. The greater inactivation of *L. monocytogenes* in Iberian type can hardly be explained by the slightly lower pH (5.7 in Iberian versus 5.9 in Serrano), and probably other non-determined intrinsic factors of the product may have contributed to these differences. In both types of ham, the lower the a_w the higher the inactivation of the pathogen.

The impact of the temperature during storage of sliced dry-cured ham was also very noticeable. At refrigeration temperatures (2 and 8 ºC) the listericidal effect of the product was limited, especially in higher a_w products (*ca*. only 1 Log reduction was achieved after 6 months of storage). On the other hand, at higher temperatures, especially at 25 ºC, the inactivation was considerably more intense, achieving between 6 and 7 Log reductions of the level of the pathogen within 2 and 3 months of storage. Reynolds et al. (2001) also reported higher inactivation of *L. monocytogenes* during storage at room temperature of post-processing inoculated dry-cured ham.

The loss of viability of *L. monocytogenes* in dry-cured ham under the tested storage conditions can be explained by the metabolic exhaustion phenomenon associated with antimicrobial hurdles. The characteristics of the product, pH and mainly a_w of the ham did not allow the growth of the pathogen. In non-growth conditions of shelf-stable foods, the microorganisms tend to die, and die more rapidly when the conditions of shelf-stability approach the limits of growth, for example, as in this case, at room temperature (Leistner, 2000). These results point out that proper storage conditions of dry-cured ham would favor inactivation of *L. monocytogenes* contaminating the finished products before their release to retail, distribution, export, etc. Thus, dry-cured ham manufacturers can take advantage of this phenomenon as an opportunity to design a control measure into their production process, e.g. a validated post-lethality treatment, in order to minimize the risk of non-compliance of the zero-tolerance requirements.

3.2. *Inactivation kinetics of* L. monocytogenes on dry-cured ham. *Primary modeling*

Four primary inactivation models (Log-linear, Log-linear with tail, Log-linear with shoulder and Weibull) were fitted to inactivation data. The estimated kinetic parameters obtained using Log-linear based models together with the goodness of fit are summarized in supplementary material (Table S1 for Serrano and Table S2 for Iberian dry-cured ham). The fitted kinetic parameter values and measures of goodness of fit obtained for the Weibull model are reported in Table 3. The graphical results of the Weibull model fit to inactivation of *L. monocytogenes* on sliced vacuum-packed dry-cured ham, according to the type of ham, a_w and storage temperature are shown in Figure 1. The Weibull model with two parameters (δ and p) allowed the fitting of different inactivation shapes through the p parameter and resulted in the best fit of the experimental data as indicated by the lower RSS and the higher R^2_{adj} values in comparison with the Log-linear based models. Therefore, the Weibull model was selected to describe the inactivation kinetics of *L. monocytogenes* on dry-cured ham.

The estimated δ parameter, e.g. the time needed for the first Log reduction, was systematically lower in Iberian than in Serrano ham, confirming that Iberian type favored an earlier inactivation of *L. monocytogenes*. In addition, the higher the storage temperature the lower the δ, pointing out that increasing up to room temperature favored the inactivation of the pathogen. On the other hand, the opposite effect was found for a_w, as the higher the a_w, the higher the δ. At refrigeration temperatures (e.g. 2 and 8 ºC), especially for products with high a_w (>0.91), the δ showed values higher than 100 days, indicating that refrigeration slowed down the metabolic reactions preventing the metabolic exhaustion *L. monocytogenes* cells.

At the highest studied storage temperature (e.g. 25 ºC) the shape of the inactivation curve (p) was highly dependent on the a_w of the product. In low a_w hams (0.85 and 0.87), *L. monocytogenes* inactivation showed a concave shape (p<1), indicating a higher inactivation at the beginning of the storage, and thus, the occurrence of a sort of tail of resistant cells. On the other hand, in products with the highest a_w (0.91), *L. monocytogenes* fate showed a convex shape (p>1), indicating lower inactivation at the beginning of the storage, and being in concordance with the highest time to the first 1 Log reduction (δ) found in higher a_w products compared to lower a_w products.

3.3. *Secondary models for* L. monocytogenes *inactivation on dry-cured ham*

Polynomial models were developed in order to quantify the impact of product a_w and storage temperature on the inactivation kinetic values obtained from the selected primary model fitting (e.g. the δ and p parameters of the Weibull model). Four different transformations were assessed, namely square root, inverse, Ln and Log.

The square root transformation of δ value was chosen for both products, Serrano and Iberian ham, as resulted with the best fit indicated by the higher R^2_{adj}. The δ parameter of both types of ham was dependent on product a_w and storage temperature. The F-test indicated that the equations for δ obtained for Serrano and Iberian hams were statistically different, thus a unique model for δ for both types of ham was not considered.

The best transformation of the p values was different depending on the type of ham. For Serrano ham, the inverse transformation of p values provided the best fit. It is noticeable that the transformed p values of *L. monocytogenes* in Serrano ham were statistically dependent on a_w but not on temperature, indicating the great effect of a_w on the shape of the inactivation curve. On the other hand, for Iberian ham the Log transformation fitted best the data and the resulting polynomial models indicated that p values were statistically dependent on temperature but also on the interaction between temperature and a_w.

The estimated parameters and the goodness of fit of the polynomial models developed for the inactivation of *L. monocytogenes* in dry-cured ham as a function of a_w and/or storage temperature are reported in Table 4.

In order to obtain refined model parameters, the equations obtained for the secondary models were combined with the selected primary model to use a single mathematical equation to fit the entire set of inactivation data though the one-step global fitting. The resulting readjusted values of the terms describing the inactivation of *L. monocytogenes* for the two types of dry-cured ham are shown in Table 4. The coefficients of equations of the global models clearly confirmed that different models were needed for Serrano and Iberian ham types because a combined model for the two types did not describe the experimental data appropriately. For each type of ham, statistical goodness of fit indices showed the one-step global models provided a better description of the inactivation data when compared to the classical two-step approach. This result was expected because the one-step global procedure fully considered the raw data, resulting in increased degrees of freedom and more accurate and robust parameter estimates (Jewell, 2012; Martino & Marks, 2007).

3.5. *Evaluation of the developed models*

After model formulation and selection based on its statistical performance to accurately describe the experimental dataset, it is important to evaluate the model predictive performance in real food systems with independently acquired data from similar food matrices. To this purpose, the Acceptable Simulation Zone (ASZ) approach was used to compare the 63 inactivation values obtained from scientific articles dealing with *L. monocytogenes* in dry-cured ham with the respective predictions provided by the developed inactivation model (Table 5). Overall, the model tended to overestimate the inactivation of the pathogen by an average of 0.3 Log units, which can be considered satisfactory taken into account that it is a slight conservative (fail-safe) prediction. In addition, for Serrano ham, 72.9 % of the predictions were within the ASZ (Table 5), proving the good predictive performance of the developed models. Due to the lack of independent data from Iberian ham, the evaluation of the developed *L. monocytogenes* inactivation model could not be properly conducted for this type of product. However, the few available data regarding Log (N/N_0) values of *L. monocytogenes* in Iberian hams collected from literature were all within the ASZ (Table 5).

3.6. *Application of developed models*

Within the alternatives recognized by the US Food Safety Inspection Service (FSIS) to control *L. monocytogenes* in RTE, the results of the present study constitute a scientific evidence that dry-cured ham can be considered an AMA/P, suppressing the growth of *L. monocytogenes* during the storage, thus making the product to fulfill the Alternative 2b requirements of the US Listeria rule (FSIS, 2015). It is worth to highlight that the listericidal effects observed in the present work during the storage of dry-cured ham could be exploited as PLT to achieve a level of control complying with Alternative 1 of US Listeria rule. For this, almost 1 Log reduction of

L. monocytogenes before dry-cured ham is released to the market should be validated. The application of validated predictive models is an accepted option to validate PLT according to the FSIS (FSIS, 2014). In this framework, the predictive models developed in this study allow to set the time necessary to reduce 1 Log the level of *L. monocytogenes* at a given storage temperature for different types of dry-cured ham as a function of their a_w. To this aim, Figure 2 shows the 1-Log iso-reduction plots enabling the easy identification of time/temperature combinations suitable for a corrective storage (as the PLT) for each type of dry-cured ham and $a_{w.}$ In the lowest a_w products, the time required to achieve 1 Log reduction was of 9 and 6 days at 25 ºC for Serrano and Iberian hams, respectively.

Considering that the estimated shelf-life of dry-cured ham is about 6 months, the application of such a short corrective storage time before product is released would be a feasible control measure as PLT, in form of a quarantine period, to reduce *L. monocytogenes* levels in products exposed to re-contamination after the drying process (e.g. during deboning, slicing, packaging) and thus, to ensure the accomplishment of the zero-tolerance policies, by operating under Alternative 1 of the Listeria rule (FSIS, 2015). This control measure could also be helpful for companies within EU aiming to meet the commercial agreements of specific clients with zero tolerance requirements to their providers.

4. Conclusions

The physicochemical characteristics, mainly low a_w, make dry-cured ham not only listeriostatic but listericidal and thus, compromising the viability of *L. monocytogenes* depending on the product a_w and storage temperature.

In the framework of the design of risk minimization strategies, the quantified listericidal effect of dry-cured ham can be used to establish a corrective storage, a feasible low-cost control measure taking advantage of the product characteristics, as a PLT in products exposed to re-contamination after the drying process (e.g. during deboning, slicing, packaging). This measure could be implemented by the dry-cured ham producers to guarantee the fulfilment of restrictive legal and commercial requirements regarding *L. monocytogenes* derived from zero tolerance policies (such as the US Listeria rule).

Acknowledgements

This work was supported by Listeria 0 project (INIA-PA 14/83 Lote 2) and by the CERCA Programme/Generalitat de Catalunya. The authors thank Dr. Margarita Medina (INIA, Madrid) for kindly providing the strains of *Listeria monocytogenes.*

References

ANICE (2019). El sector cárnico. In: Asociación Naiconal de Industrias de la Carne de España. https://www.anice.es/industrias/area-de-prensa/el-sector-carnico-espanol_213_1_ap.html [accessed 04/08/2019].

Australian Government (2017). Australia New Zealand Food Standards Code – Standard 1.6.1 – Microbiological limits in food, Schedule 27. https://www.legislation.gov.au/Details/F2018C00939 [accessed on 04/08/2019].

Bover-Cid, S., Belletti, N., Aymerich, T., & Garriga, M. (2015). Modeling the protective effect of a_w and fat content on the high pressure resistance of *Listeria monocytogenes* in dry-cured ham. *Food Research International, 75*, 194-199.

Bover-Cid, S., Jofré, A., & Garriga, M. (2016). Inactivation kinetics of *Salmonella* and *L. monocytogenes* in dry-cured ham stored at different temperatures. Proceedings of 25th International ICFMH Conference - FoodMicro 2016. One health meets food microbiology (Dublin, Ireland), p. 472.

Bover-Cid, S., Serra-Castelló, C., Dalgaard, P., Garriga, M., & Jofré, A. (2019). New insights on *Listeria monocytogenes* growth in pressurised cooked ham: A piezo-stimulation effect enhanced by organic acids during storage. *International Journal of Food Microbiology, 290*, 150-158.

Cabedo, L., Picart-Barrot, L., & Teixidó-Canelles, A. (2008). Prevalence of *Listeria monocytogenes* and *Salmonella* in ready-to-eat food in Catalonia, Spain. *Journal of Food Protection, 71*(4), 855–859.

Costa-Corredor, A., Serra, X., Arnau, J., & Gou, P. (2009). Reduction of NaCl content in restructured dry-cured hams: Post-resting temperature and drying level effects on physicochemical and sensory parameters. *Meat Science, 83*(3), 390-397.

EURL Lm (2014). Technical guidance document for conducting shelf-life studies on *Listeria monocytogenes* in ready-to-eat foods. Version 3 - 06/06/2014. Maisons-Alfort, France: EURL *Listeria monocytogenes*, ANSES, pp. 47.

European Commission (2005). Commission Regulation (EC) No 2073/2005 of 15 November 2005 on microbiological criteria for foodstuffs. *Official Journal of the European Communities* vol. L 338, 1-26.

FSIS (2010). FSIS Directive 7120.1, Revision 2: Safe and suitable ingredients used in the production of meat, poultry, and egg products. Washington, D.C.

FSIS (2014). FSIS compliance guideline: controlling *Listeria monocytogenes* in post-lethality exposed ready-to-eat meat and poultry products. https://www.fsis.usda.gov/wps/wcm/connect/d3373299-50e6-47d6-a577-e74a1e549fde/Controlling-Lm-RTE-Guideline.pdf?MOD=AJPERES [accessed on 04/08/2019].

FSIS (2015). 9 CFR Part 430: Control of *Listeria monocytogenes* in ready-to-eat meat and poultry products. *Federal Register, 80*(118), 35178 -35188.

Giovannini, A., Migliorati, G., Prencipe, V., Calderone, D., Zuccolo, C., & Cozzolino, P. (2007). Risk assessment for listeriosis in consumers of Parma and San Daniele hams. *Food Control, 18*(7), 789-799.

Health Canada (2011). Policy on *Listeria monocytogenes* in Ready-to-Eat foods (DF-FSNP 0071). F. D. Bureau of Microbial Hazards, Health Products and Food Branch, pp. 74.

Hereu, A., Dalgaard, P., Garriga, M., Aymerich, T., Bover-Cid, S., 2012. Modeling the high pressure inactivation kinetics of *Listeria monocytogenes* on RTE cooked meat products. *Innovative Food Science & Emerging Technologies, 16*, 305-315.

Hereu, A., Bover-Cid, S., Garriga, M., & Aymerich, T. (2012). High hydrostatic pressure and biopreservation of dry-cured ham to meet the Food Safety Objectives for *Listeria monocytogenes*. *International Journal of Food Microbiology, 154*(3), 107-112.

Jemmi, T., Pak, S. I., & Salman, M. D. (2002). Prevalence and risk factors for contamination with Listeria monocytogenes of imported and exported meat and fish products in Switzerland, 1992-2000. *Preventive Veterinary Medicine, 54*(1), 25-36.

Jewell, K. (2012). Comparison of 1-step and 2-step methods of fitting microbiological models. *International Journal of Food Microbiology, 160*(2), 145-161.

Leistner, L. (2000). Basic aspects of food preservation by hurdle technology. *International Journal of Food Microbiology, 55*(1-3), 181-186.

Lorido, L., Estévez, M., Ventanas, J., & Ventanas, S. (2015). Comparative study between Serrano and Iberian dry-cured hams in relation to the application of high hydrostatic pressure and temporal sensory perceptions. *LWT-Food Science and Technology, 64(2)*, 1234-1242.

Martín, B., Perich, A., Gómez, D., Yangüela, J., Rodríguez, A., Garriga, M., & Aymerich, T. (2014). Diversity and distribution of *Listeria monocytogenes* in meat processing plants. *Food Microbiology, 44*, 119-127.

Martino, K. J., & Marks, B. P. (2007). Comparing Uncertainty Resulting from Two-Step and Global Regression Procedures Applied to Microbial Growth Models. *Journal of Food Protection174;, 70*(12), 2811-2818.

Medina, M. (2017). Inactivación de *L. monocytogenes* en el proceso de elaboración del jamón curado. *Transferencia de resultados de proyectos INIA sobre Listeria monocytogenes en productos cárnicos*). Madrid. http://wwwsp.inia.es/Investigacion/OtrasUni/TransferenciaTecnologia/ForosINIA/Lmonocytogenes/Lists/Presentaciones/Attachments/2/02MargaritaMedina.pdf [accessed 16/08/2019].

Møller, C. O. A., Ilg, Y., Aabo, S., Christensen, B. B., Dalgaard, P., & Hansen, T. B. (2013). Effect of natural microbiota on growth of Salmonella spp. in fresh pork – A predictive microbiology approach. *Food Microbiology, 34*(2), 284-295.

Morales, P., Calzada, J., & Nuñez, M. (2006). Effect of high-pressure treatment on the survival of *Listeria monocytogenes* Scott A in sliced vacuum-packaged iberian and serrano cured hams. *Journal of Food Protection, 69*(10), 2539–2543.

Ortiz, S., López, V., Villatoro, D., López, P., Carlos Davila, J., & Martínez-Suárez, J. V. (2010). A 3-year surveillance of the genetic diversity and persistence of *Listeria monocytogenes* in an Iberian pig slaughterhouse and processing plant. *Foodborne Pathogens and Disease, 7*(10), 1177-1184.

Prencipe, V. A., Rizzi, V., Acciari, V., Iannetti, L., Giovannini, A., Serraino, A., Calderone, D., Rossi, A., Morelli, D., Marino, L., Migliorati, G., & Caporale, V. (2012). *Listeria monocytogenes* prevalence, contamination levels and strains characterization throughout the Parma ham processing chain. *Food Control, 25*(1), 150-158.

Reynolds, A. E., Harrison, M. A., Rose-Morrow, R., & Lyon, C. E. (2001). Validation of dry cured ham process for control of pathogens. *Journal of Food Science, 66*(9), 1373-1379.

.

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Talon, R., Lebert, I., Lebert, A., Leroy, S., Garriga, M., Aymerich, T., Drosinos, E. H., Zanardi, E., Ianieri, A., Fraqueza, M. J., Patarata, L., & Laukovà, A. (2007). Traditional dry fermented sausages produced in small-scale processing units in Mediterranian countries and Slovakia. 1; Microbial ecosystems of processing environments. *Meat Science, 77*, 570-579.

Uyttendaele, M., De Troy, P., & Debevere, J. (1999). Incidence of Listeria monocytogenes in different types of meat products on the Belgian retail market. *International Journal of Food Microbiology, 53*, 75–80.

Figure captions

Figure 1. Behavior of *L. monocytogenes* in Serrano and Iberian dry-cured hams with different a_w and stored at 2, 8, 15 or 25 °C. Symbols represent the observed pathogen inactivation, Log (N/N_0), and lines show the fit of the primary Weibull model.

Figure 2. Predicted time for 1 Log reduction of *L. monocytogenes* according to the storage temperature in Serrano (a) and Iberian (b) hams with different a_w.

Figure 1

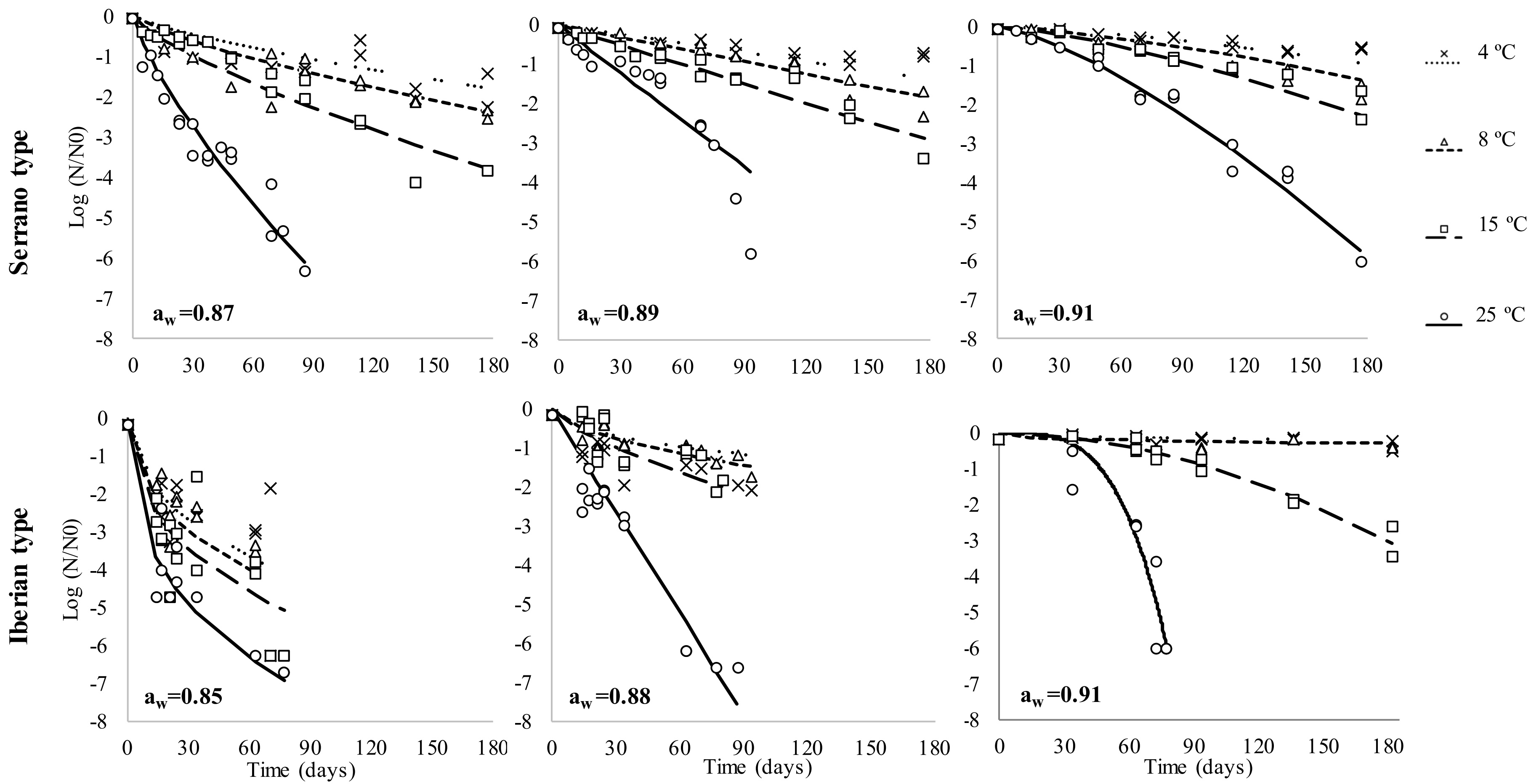
Serrano type
Iberian type
Log (N/N0)
Time (days)
aw=0.87
aw=0.89
aw=0.91
aw=0.85
aw=0.88
aw=0.91
4 ºC
8 ºC
15 ºC
25 ºC

Figure 2

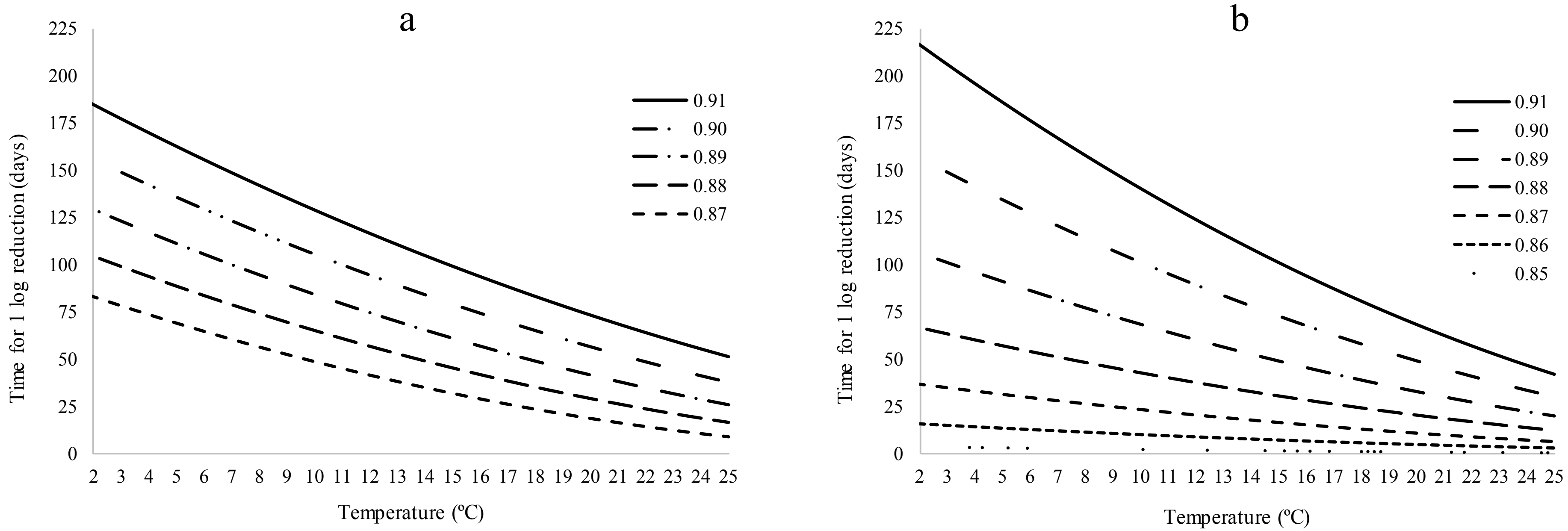
a
Time for 1 log reduction (days)
Temperature (ºC)
0.91
0.90
0.89
0.88
0.87
b
Time for 1 log reduction (days)
Temperature (ºC)
0.91
0.90
0.89
0.88
0.87
0.86
0.85

Table S1. Primary inactivation models (Log-linear, Log-linear with shoulder and Log-linear with tail) used to fit the *L. monocytogenes* inactivation data (Log N/N_0) as a function of time (days) on Serrano dry-cured ham.

Primary inactivation model	**Dry-cured ham a_w**	**Temperature** (ºC)	k_{max} (1/days)	*Log N_{res}* (Log (N/N_0))	***Shoulder*** (days)	**RSS**	R^2_{adj}
Log-linear							
	0.87	2	0.02	-	-	2.414	0.546
	0.87	8	0.03	-	-	2.368	0.731
	0.87	15	0.05	-	-	1.400	0.947
	0.87	25	0.15	-	-	4.186	0.917
	0.89	2	0.01	-	-	0.342	0.732
	0.89	8	0.03	-	-	0.624	0.906
	0.89	15	0.04	-	-	1.246	0.903
	0.89	25	0.11	-	-	5.761	0.842
	0.91	2	0.01	-	-	0.147	0.783
	0.91	8	0.02	-	-	0.216	0.951
	0.91	15	0.02	-	-	0.535	0.902
	0.91	25	0.07	-	-	2.254	0.947
Log-linear with shoulder							
	0.87	2	0.03	-	0.0	3.663	0.311
	0.87	8	0.04	-	0.0	3.434	0.609
	0.87	15	0.05	-	0.0	1.406	0.947
	0.87	25	0.18	-	0.0	7.474	0.853
	0.89	2	0.01	-	0.0	0.529	0.584
	0.89	8	0.02	-	0.0	0.665	0.900
	0.89	15	0.04	-	0.0	1.289	0.899
	0.89	25	0.12	-	9.0	5.118	0.860
	0.91	2	0.01	-	0.0	0.156	0.771
	0.91	8	0.02	-	0.0	0.236	0.947
	0.91	15	0.02	-	0.0	0.546	0.900
	0.91	25	0.08	-	27.2	1.466	0.966
Log-linear with tail							
	0.87	2	0.03	-2.31	-	3.663	0.311
	0.87	8	0.04	-2.28	-	3.153	0.641
	0.87	15	0.05	-4.45	-	1.406	0.947
	0.87	25	0.18	-5.81	-	7.530	0.851
	0.89	2	0.02	-4.00	-	0.200	0.843
	0.89	8	0.02	-2.01	-	0.665	0.900
	0.89	15	0.04	-2.88	-	1.289	0.899
	0.89	25	0.10	-4.00	-	5.925	0.837
	0.91	2	0.01	-0.58	-	0.120	0.823
	0.91	8	0.02	-2.33	-	0.236	0.947
	0.91	15	0.02	-1.88	-	0.546	0.900
	0.91	25	0.06	-5.28	-	2.957	0.930

Table S2. Primary inactivation models (Log-linear, Log-linear with shoulder and Log-linear with tail) used to fit the *L. monocytogenes* inactivation data (Log N/N_0) as a function of time (days) on Iberian dry-cured ham.

Primary inactivation model	**Dry-cured ham a_w**	**Temperature** (ºC)	k_{max} (1/days)	$Log\ N_{res}$ (Log (N/N_0))	**Shoulder** (days)	**RSS**	R^2_{adj}
Log-linear							
	0.85	2	0.1	-	-	16.364	0.409
	0.85	8	0.1	-	-	6.725	0.536
	0.85	15	0.1	-	-	18.536	0.696
	0.85	25	0.2	-	-	20.090	0.654
	0.88	2	0.0	-	-	2.192	0.567
	0.88	8	0.0	-	-	1.018	0.680
	0.88	15	0.0	-	-	2.807	0.602
	0.88	25	0.2	-	-	4.141	0.937
	0.91	2	0.0	-	-	0.290	0.400
	0.91	8	0.0	-	-	0.958	0.229
	0.91	15	0.0	-	-	1.652	0.901
	0.91	25	0.2	-	-	11.779	0.810
Log-linear with shoulder							
	0.85	2	0.1	-	0.0	23.695	0.144
	0.85	8	0.2	-	0.0	12.750	0.120
	0.85	15	0.2	-	0.0	30.483	0.499
	0.85	25	0.3	-	0.0	49.438	0.149
	0.88	2	0.1	-	0.0	4.063	0.198
	0.88	8	0.0	-	0.0	1.589	0.500
	0.88	15	0.1	-	0.0	2.948	0.582
	0.88	25	0.2	-	0.0	5.822	0.912
	0.91	2	0.0	-	6.1	0.295	0.390
	0.91	8	0.0	-	14.0	0.956	0.231
	0.91	15	0.1	-	50.6	0.683	0.959
	0.91	25	0.2	-	27.9	7.758	0.875
Log-linear with tail							
	0.85	2	0.3	-2.89	-	15.477	0.441
	0.85	8	0.3	-2.77	-	3.828	0.736
	0.85	15	0.4	-4.83	-	24.718	0.594
	0.85	25	0.5	-5.40	-	17.837	0.693
	0.88	2	0.1	-4.58	-	4.063	0.198
	0.88	8	0.0	-3.41	-	1.589	0.500
	0.88	15	0.1	-4.43	-	2.948	0.582
	0.88	25	0.2	-16.98	-	5.822	0.912
	0.91	2	0.0	-0.20	-	0.318	0.342
	0.91	8	0.0	-0.32	-	0.761	0.388
	0.91	15	0.0	-2.52	-	3.142	0.812
	0.91	25	0.1	-11.50	-	14.311	0.770

Table 1. *Listeria monocytogenes* strains used in this work[a].

Strain	Genotype	Serotype
EF 051005/3/A	S2	1/2a
EF 151105/2/A	S4-2	1/2b
EF 010207/24/A	S12-1	1/2c
EF 270406/1/A	S7-2	4b

[a]: strains were isolated from pork meat industrial environment (Medina, 2017; Ortiz, López, Villatoro, López, Carlos Davila, & Martínez-Suárez, 2010)

Table 2. Primary inactivation models used to fit the *L. monocytogenes* inactivation data as a function of time.

Model	Equation[a]
Weibull	$Log(N/N_0) = -\left(\frac{t}{\delta}\right)^p$
Log-linear	$Log(N/N_0) = -\left(\frac{k_{max} \cdot t}{\ln(10)}\right)$
Log-linear with tail	$Log(N/N_0) = \mathrm{Log}\left[\left(1 - 10^{Log(N_{res})}\right) \cdot e^{(-k_{max} \cdot t)} + 10^{Log(N_{res})}\right]$
Log-linear with shoulder	If $t \leq shoulder$; $Log(N/N_0) = 0$ If $t > shoulder$; $Log(N/N_0) = -\left(\frac{k_{max} \cdot t}{\ln(10)}\right) + Log\left(\frac{e^{(k_{max} \cdot shoulder)}}{1 + \left[e^{(k_{max} \cdot shoulder)} - 1\right] \cdot e^{(-k_{max} \cdot t)}}\right)$

[a] *Log* (N/N_0): bacterial inactivation at specific time (t); Log N_{res}: inactivation tail (maximum inactivation); t: time (days); δ: time for the first Log reduction; p: shape of the inactivation curve; k_{max}: inactivation rate; *shoulder*: time before inactivation (initial resistance to stress).

Table 3. Estimated inactivation kinetic parameters resulting from fitting the primary Weibull model to the *L. monocytogenes* inactivation data obtained for dry-cured ham with different a_w and stored at different storage temperatures.

Product	**Experimental conditions**		**Kinetic parameters**		**Goodness of fit**[a]		
Dry-cured ham type	a_w	**Temperature (ºC)**	δ **(days)**[b]	P[b]	**n**	**RSS**	R^2_{adj}
Serrano	0.87	2	34.9 ± 16.2	0.32 ± 0.13	16	0.123	0.677
		8	32.2 ± 10.2	0.48 ± 0.12	16	0.129	0.795
		15	47.5 ± 3.6	1.20 ± 0.08	19	0.062	0.947
		25	6.0 ± 1.1	0.65 ± 0.06	19	0.164	0.945
	0.89	2	>180	0.46 ± 0.08	16	0.013	0.860
		8	101.4 ± 5.2	1.28 ± 0.15	16	0.037	0.922
		15	64.2 ± 5.6	1.04 ± 0.12	19	0.075	0.900
		25	39.5 ± 3.4	1.93 ± 0.23	16	0.197	0.924
	0.91	2	>180	0.77 ± 0.16	16	0.010	0.798
		8	113.8 ± 3.9	1.14 ± 0.10	16	0.015	0.953
		15	105.3 ± 5.3	1.19 ± 0.14	16	0.035	0.911
		25	51.5 ± 3.4	1.41 ± 0.09	16	0.082	0.973
Iberian	0.85	2	2.0 ± 2.6	0.36 ± 0.16	16	12.675	0.542
		8	1.8 ± 1.3	0.30 ± 0.10	14	2.764	0.809
		15	2.0 ± 1.3	0.47 ± 0.10	18	14.073	0.769
		25	0.3 ± 0.2	0.33 ± 0.06	16	6.325	0.891
	0.88	2	15.8 ± 6.2	0.32 ± 0.10	16	1.291	0.745
		8	46.2 ± 6.5	0.46 ± 0.11	16	0.777	0.756
		15	38.3 ± 6.3	0.74 ± 0.20	17	2.690	0.559
		25	7.3 ± 1.2	0.79 ± 0.06	16	3.548	0.946
	0.91	2	-[c]	0.39 ± 0.31	16	0.363	0.249
		8	-[c]	0.32 ± 0.32	16	1.042	0.161
		15	100.8 ± 5.0	1.89 ± 0.18	16	0.777	0.954
		25	46.8 ± 5.2	3.55 ± 0.85	12	4.823	0.922

[a] n: number of inactivation data, Log (N/N_0), included for fitting, RSS: residual sum of squares; R^2_{adj}: adjusted coefficient of determination.

[b] Parameter estimate ± standard error.

[c] No inactivation was recorded. δ had an infinitive value.

Table 4. Estimated coefficients of the polynomial models resulting from the fitting to values of the primary inactivation kinetics.

		Coefficients of the polynomial models[a]							Goodness of fit[b]		
Serrano dry-cured ham		**a**	**b**	**c**	**d**	**e**	**f**	**g**	**P**	**RSS**	**R^2_{adj}**
Secondary polynomial models	$\sqrt{\delta} = a + b\cdot a_w + c\cdot a_w\cdot T$	-132.60 ± 34.32	163.19 ± 38.57	-0.33± 0.08	-	-	-	-	3	42.782	0.746
	$1/p = e + f\cdot a_w$	-	-	-	-	28.66 ± 10.84	-30.84 ± 12.18	-	2	4.748	0.330
Global model	$\text{Log}\,(N/N_0) = \text{Log}\,(N/N_0)_{initial} - \left(\frac{t}{(a + b\cdot a_w + c\cdot a_w\cdot T)^2}\right)^{\frac{1}{e + f\cdot a_w}}$	-88.52 ± 5.22	112.83 ± 5.84	-0.31 ± 0.01	-	13.93 ± 1.71	-14.51 ± 1.90	-	5	24.778	0.919
Iberian dry-cured ham											
Secondary polynomial models	$\sqrt{\delta} = a + b\cdot a_w^2 + c\cdot T + d\cdot a_w\cdot T$	-90.99 ± 12.66	127.02 ± 16.31	3.96 ± 1.65	-4.66 ±1.88	-	-	-	4	15.162	0.913
	$\text{Log}\,p = e + f\cdot T + g\cdot a_w\cdot T$	-	-	-	-	-0.52 ± 0.08	-0.53 ± 0.10	0.63 ± 0.12	3	0.185	0.824
Global model	$\text{Log}\,(N/N_0) = \text{Log}\,(N/N_0)_{initial} - \left(\frac{t}{(a + b\cdot a_w^2 + c\cdot T + d\cdot a_w\cdot T)^2}\right)^{10^{(e + f\cdot T + g}}$	-90.11± 7.44	127.42 ± 10.15	4.29 ± 0.65	-5.11 ± 0.76	-0.34 ± 0.07	-0.48 ± 0.05	0.56 ± 0.06	7	71.069	0.892

[a] Parameter estimates ± standard error.

[b] P: number of estimated parameters of the model; RSS: residual sum of squares; R^2_{adj}: adjusted coefficient of determination.

Table 5. Comparison of observed and predicted *L. monocytogenes* inactivation in Serrano and Iberian dry-cured hams.

Ref[a]	Dry-cured ham	a_w	Temperature (ºC)	Time (days)	Observed inactivation (Log(N/N$_0$))	Predicted inactivation (Log(N/N$_0$))	Observed-Predicted inactivation
[1]	Serrano	0.88	4	7	-0.71	-0.11	*-0.6*
		0.88	8	7	-0.59	-0.13	*-0.5*
		0.88	4	30	-1.24	-0.38	*-0.9*
		0.88	8	30	-1.38	-0.46	*-0.9*
		0.88	4	60	-1.35	-0.68	*-0.7*
		0.88	8	60	-1.25	-0.83	*-0.4*
[2]	Serrano	0.93	2	15	-0.05	0.00	*-0.1*
		0.93	2	15	0.01	0.00	*0.0*
		0.93	2	15	0.08	0.00	*0.1*
		0.93	2	15	-0.16	0.00	*-0.2*
		0.93	2	27	-0.04	-0.01	*0.0*
		0.93	2	27	-0.08	-0.01	*-0.1*
		0.93	2	41	-0.07	-0.02	*-0.1*
		0.93	2	43	-0.22	-0.02	*-0.2*
		0.93	2	55	-0.08	-0.03	*-0.1*
		0.93	2	70	-0.08	-0.06	*0.0*
		0.93	2	97	-0.25	-0.12	*-0.1*
		0.93	2	166	-0.22	-0.40	*0.2*
		0.93	2	166	-0.20	-0.40	*0.2*
		0.93	8	15	-0.28	0.00	*-0.3*
		0.93	8	15	-0.26	0.00	*-0.3*
		0.93	8	15	-0.14	0.00	*-0.1*
		0.93	8	15	-0.07	0.00	*-0.1*
		0.93	8	27	-0.16	-0.01	*-0.2*
		0.93	8	27	-0.27	-0.01	*-0.3*
		0.93	8	41	-0.26	-0.03	*-0.2*
		0.93	8	43	-0.12	-0.03	*-0.1*
		0.93	8	55	-0.37	-0.05	*-0.3*
		0.93	8	70	-0.15	-0.09	*-0.1*
		0.93	8	97	-0.67	-0.19	*-0.5*
		0.93	8	166	-1.20	-0.66	*-0.5*
		0.93	15	15	-0.23	-0.01	*-0.2*
		0.93	15	15	-0.46	-0.01	*-0.5*
		0.93	15	15	-0.23	-0.01	*-0.2*
		0.93	15	15	-0.20	-0.01	*-0.2*
		0.93	15	27	-0.46	-0.02	*-0.4*
		0.93	15	27	-0.23	-0.02	*-0.2*
		0.93	15	41	-0.15	-0.05	*-0.1*
		0.93	15	43	-0.26	-0.06	*-0.2*
		0.93	15	55	-0.57	-0.10	*-0.5*
		0.93	15	70	-0.88	-0.18	*-0.7*

		0.93	15	70	-0.92	-0.18	*-0.7*
		0.93	15	98	-1.36	-0.38	*-1.0*
		0.93	25	7	-0.18	0.00	*-0.2*
		0.93	25	7	-0.22	0.00	*-0.2*
		0.93	25	7	0.03	0.00	*0.0*
		0.93	25	7	-0.21	0.00	*-0.2*
		0.93	25	15	-0.29	-0.02	*-0.3*
		0.93	25	15	-0.17	-0.02	*-0.2*
		0.93	25	15	-0.21	-0.02	*-0.2*
		0.93	25	15	-0.25	-0.02	*-0.2*
		0.93	25	41	-0.92	-0.19	*-0.7*
		0.93	25	43	-0.81	-0.21	*-0.6*
		0.93	25	43	-0.94	-0.21	*-0.7*
		0.93	25	55	-0.98	-0.36	*-0.6*
[3]	Serrano	0.92	8	5	-0.52	0.00	*-0.5*
		0.92	8	13	-0.65	-0.01	*-0.6*
		0.92	8	32	-0.79	-0.06	*-0.7*
		0.92	8	61	-1.04	-0.18	*-0.9*
[3]	Iberian	0.88	8	5	-0.67	-0.27	*-0.4*
		0.88	8	13	-0.84	-0.46	*-0.4*
		0.88	8	32	-0.69	-0.79	*0.1*
		0.88	8	61	-0.7	-1.15	*0.5*

[a] References: *[1]* Morales et al. (2006); *[2]* Bover-Cid et al. (2016) *[3]* Hereu et al. (2012)

Highlights

- Dry-cured ham is not only listeriostatic, it may be listericidal
- Listericidal effect was quantified as a function of a_w and storage temperature
- Iberian ham type favors an early inactivation of *L. monocytogenes*
- A low-cost control measure is proposed as a post-lethality treatment

Authors have no conflict of interests