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EVALUATION OF PREDICTIVE MODELS DESCRIBING THE SURVIVAL OF *LISTERIA MONOCYTOGENES* ON DRY-AGED MEAT

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I. INTRODUCTION

Dry-aged meat is increasingly appreciated for its enhanced flavor and tenderness, driving market expansion in the EU, US, and Asia [1]. However, the environmental conditions that favor quality development, such as controlled temperature, relative humidity, and air-flow, can also influence microbial dynamics. Depending on these conditions and intrinsic physicochemical parameters (e.g., pH and water activity (a_w)), dry-aged meat may or may not support pathogen growth [2]. The European Food Safety Authority (EFSA) has highlighted *Listeria monocytogenes* and *Yersinia enterocolitica* as pathogens of concern in this context, given their ability to grow at refrigeration temperatures typical of meat dry-aging conditions [3]. Despite these concerns, research on pathogen behavior during dry-aging remains limited and often inconsistent, particularly regarding the potential for *L. monocytogenes* inactivation on the surface of meat due to drying process. Predictive microbiology offers powerful tools for evaluating microbial risks during food processing, yet applications to dry-aged meat remain scarce. Growth/no-growth (G/NG) boundary models estimate the probability of microbial proliferation under specific combination of environmental conditions, whereas survival models predict inactivation kinetics under suboptimal or non-growing conditions. To address this knowledge gap, this study aimed to (i) retrieve survival data of *L. monocytogenes* in dry-aged meat from the literature, (ii) identify existing G/NG and survival models applicable to dry-aged conditions, and (iii) evaluate model performance by comparing predictions with retrieved experimental data.

II. MATERIALS AND METHODS

A literature review was conducted using ScienceDirect, Scopus, and PubMed to identify English-language studies reporting survival of *L. monocytogenes* on meat during dry-ageing. In the expected scaricity of relevant data, studies on dry-cured meat and similar products were considered. Inclusion criteria required studies to report temperature, pH, and a_w values. For meat products different from dry-aged meat, only those falling within the physicochemical range of pH 5.5–6.3 and a_w 0.880–0.997, consistent with literature reported values for dry-aged meat, were retained. Data extracted included time, temperature, pH, a_w, and *L. monocytogenes* counts. Data available as plots were digitized using WebPlotDigitizer. Predictive models (G/NG and survival) relevant to meat matrices were identified based on their validation range and inclusion of key parameters.
To account for dynamic changes in product characteristics during dry-aging, the selected models were implemented in an integrated format with 0.5-day time steps, allowing continuous adjustment of environmental variables. When G/NG model output indicated a probability of growth ≤ 0, survival models were used to estimate the pathogen inactivation as log reductions ($\log(N/N_0)$), which were then compared to observed data. Predictive performance was assessed using the Acceptable Simulation Zone (ASZ) approach, with simulations deemed acceptable if ≥70% of predictions fell within ±0.5 log units of experimental values.

III. RESULTS AND DISCUSSION

Eleven studies met the inclusion criteria, providing a total of 28 inactivation profiles: 7 from dry-aged meat, 6 from dry-cured ham, 1 from dry-cured loin, and 14 from fermented sausages. No predictive models developed or validated specifically for *L. monocytogenes* survival on dry-aged meat were identified. However, models developed for analogous products, such as dry-cured ham and fermented sausages, were retrieved.
Among these, the model by Polese et al. [4], a simplified G/NG interface model, based on the independent action of factors, as in the gamma approach, was used to assess the growth/no-growth interface. When this model predicted a growth probability ≤0, survival was simulated using the empirical global polynomial models by Serra-Castelló et al. [5], which quantify the impact of a_w and storage temperature on the inactivation of *L. monocytogenes* in Spanish dry-cured hams (Iberian and Serrano). In parallel, the approach of Coroller et al. [6] based on a gamma concept cardinal model was implemented. This model characterizes the impact of individual environmental factors (γXi) on bacterial growth, when the γ value for a factor or interaction is 0, growth is inhibited, and survival models are applied. Coroller's

model was paired with both the Serra-Castelló inactivation models and a Weibull-based survival model also developed by Coroller et al. [6] incorporating a secondary model with gamma-derived resistance parameters.Time-dependent changes in a_w and pH were modeled through interpolation using regression, allowing continuous updates during simulation.

Simulation performances varied depending on the models' combination used. Growth/no-growth predictions from the Polese and Coroller models were largely consistent. However, major discrepancies were observed in the extent of predicted inactivation between the Serra-Castelló and Coroller survival models, with the latter showing heightened sensitivity to a_w changes and predicting greater reductions of *L. monocytogenes*, often by several order of magnitude, than both the Serra-Castelló model and the observed data. Smaller differences were noted between the Iberian and Serrano ham models developed by Serra-Castelló et al. with the Serrano ham model showing the best overall performance in predicting the fate of the pathogen.

IV. CONCLUSION

This study highlights the scarcity of experimental data on *L. monocytogenes* behavior in dry-aged meat, which limits the full validation of predictive models specifically for this product. Nonetheless, the evaluated models, originally developed for dry-cured and fermented products, showed promising predictive capabilities under dry-aging conditions, particularly where low a_w is the principal hurdle to microbial growth. While the evaluated models demonstrated promising behavior, their application to dry-aged meat should be approached with caution, and further experimental data are needed before they can be reliably used in risk assessment.

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