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Application of a mathematical model for prediction of Salmonella enterica behavior during manufacturing of Brazilian pork salami

Werlang G.[1], Vieira T.[1], Costa E.[2], Cardoso M.[1]

[1]Federal University of Rio Grande do Sul, Preventive Veterinary Medicine, Porto Alegre, Brazil, [2]Federal University of Rio Grande do Sul, EpiLab, Porto Alegre, Brazil

Introduction

Salami is a ready-to-eat product commonly consumed in Brazil and the presence of *Salmonella enterica* in this product has been reported (PETER *et al.* 2012). So far, no mandatory formulation and maturation protocol has been established (BRASIL, 2000). Besides, heat treatment is not performed, and bacterial inactivation will depend on the reduction of the pH and water activity during processing. Since mathematical models generate predictions that can be used for determining efficient maturation protocols, the aims of this study were to (i) evaluate the behaviour of a cocktail of *S. enterica* serovars during the maturation process of the Brazilian salami; (ii) test the suitability of the "gamma concept" model according to Coroller et al. (2015) for the prediction of growth/inactivation of *S. enterica* in a baseline study and (iii) perform the validation of this model.

Material and Methods

The salami formulation and maturation protocols were obtained from three Brazilian meat industries. Then, 50 and 20 salami pieces in the baseline and validation study, respectively, were prepared and inoculated with a cocktail of five strains of *S. enterica*: (1) S. Typhimurium ATCC 14028; (2) *S.* Typhimurium, (1) *S.* Infantis and (1) *S.* Derby. Salami pieces were ripened at different scenarios: *i.* fermentation at 30ºC and drying at 20ºC in the baseline study; *ii.* fermentation at 25ºC and drying at 18ºC in the validation study.
Periodical samplings for *S. enterica* quantification, water activity (a_w) and pH analysis were performed during maturation and curves were constructed. For this, on each sample time, *S. enterica* populations were enumerated by direct plating on Xylose Lysine Desoxycholate (Oxoid) added with an agar layer of Tryptic Soy Agar (Oxoid) accordingly to Kang; Fung (2000). Three colonies per sample were isolated and confirmed for *S. enterica*. The water activity of the salami samples was measured in Lab Touch - Aw (Novasin) apparatus, while the pH was measured on pH-meter DM-22 (Digimed).
Counts of *Salmonella* observed in the baseline and validation study were analysed by Bayesian inference to infer the distribution of the concentration per gram. Values of pH and room temperature were fitted by linear interpolation and water activity values where fitted in a differential equation accounting for exponential decay. The values in the baseline study were inserted in the mathematical "gamma concept" model where the bacterial growth was modelled using cardinal values of these variables and Weibull model for bacterial inactivation, according to Coroller et al. (2015). The adjusted growth/inactivation parameters (μ_{opt}, $\delta 1$, $\delta 2$, α) from the baseline study were applied in the validation of the model and tested with values from validation study.

Results

Observed curves in baseline study showed that *S. enterica* population increased 1.23 log cfu.g^{-1} in the first 21 hours and decreased 4.95 log cfu.g^{-1} after 941 hours of maturation. In the validation study, an increase of 0.54 log cfu.g^{-1} in the first 26 hours was observed followed by a 5.55 log cfu.g^{-1} inactivation after 1.121 hours of maturation.
The pH drop near to 5.3 occurred at 66 and 48 hours in the baseline and validation study, respectively. In both studies a_w decline ranged from 0.9570 to 0.7568: in the baseline study there was a daily decrease of 0.0050; while in the validation study this value was 0.0042. The a_w represented the threshold in the growth/inactivation interface; when the minimum cardinal value for water activity used in this model (0.951) was achieved (26 hours of maturation), bacterial inactivation started. The parameters (95% IC) adjusted in the model were: (h^{-1}) = 2.54 (2.545 - 3.03), $\delta 1(h)$ = 1588.06 (1587.99 - 1891.68), $\delta 2(h)$ = 163299.72 (163292.80 - 194520.80) e α = 0.02158 (0.02157 - 0.02571). The baseline model predicted well the growth/inactivation interface and the tail at the end of maturation. Linear regression of predicted compared to the observed values showed that 97.65% of the variation in the observed values could be explained by the predicted ones in the baseline study; while the application of the fitted parameters in the validation study had 95% of the variation explained.

Discussion and Conclusion

The higher maturation temperature used in the baseline study (30 and 20°C) speeded up the reduction of *S. enterica* in comparison to the validation (25 and 18ºC). These results are in concordance with Hwang et al. (2009), in which *S.* Typhimurium had higher inactivation rates when food was stored at temperatures of 21 and 30 °C when compared to 4 °C. Most of bacteria achieve the maximum growth between a_w values 0.990 and 0.995 and the reduction in a_w caused an increase in the lag phase (BEALES, 2004).

When a_w of 0,951 was achieved in salami, according to the model, *S. enterica* inactivation began and this variable was the most important regarding the start of the bacterial reduction. Thus, the drying step was the most important in the inactivation of the bacteria. Furthermore, in the baseline study the reduction of a_w was higher than in the validation of the model and this fact reflected in the *S. enterica* population reduction. Regarding the adjustment of the model, in the validation study 95% of the variation in the observed values could still be explained by the predicted ones, showing a good fit of the model for different protocols of maturation. In conclusion, this model can be applied in salami manufacture planning at industries in order to diminish the risk of *Salmonella* presence.

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