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*Publication date:*  
2018

*Document Version*  
Peer reviewed version

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*Citation (APA):*

Martinez Rios, V., & Dalgaard, P. (2018). New term for effect of temperature on pH<sub>MIN</sub>-values in cardinal parameter growth models for *Listeria monocytogenes*. Abstract from 26th International ICFMH Conference, Berlin, Berlin, Germany.

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## NEW TERM FOR EFFECT OF TEMPERATURE ON $pH_{MIN}$ -VALUES IN CARDINAL PARAMETER GROWTH MODELS FOR *LISTERIA MONOCYTOGENES*

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Cardinal parameter models for growth and growth boundary of *L. monocytogenes* (CPM-*Lm*) are popular, extensively validated and widely used for various foods in the assessment and management of risk. Interestingly, available CPM-*Lm* includes very different  $pH_{min}$ -values from 4.3 to 5.0. This can be due to differences in the mathematical terms used to estimate  $pH_{min}$ -values and to strain variability as often suggested. However, the experimental conditions used to estimate  $pH_{min}$ -values remain little studied although the minimal pH-values supporting growth is known to depend on other environmental conditions including temperature. Therefore, the objective was to study the influence of temperature on  $pH_{min}$ -values of *L. monocytogenes* as used in CPM-*Lm*.

The combined effect of temperature and pH on maximum specific growth rate ( $\mu_{max}$ ) for eight different *L. monocytogenes* strains were determined experimentally by using Bioscreen C or collected from the literature (287  $\mu_{max}$ -values). 16 pH-values from 4.4 to 6.8 and eight temperatures from 5°C to 37°C were studied. At each temperature the  $pH_{min}$ -value was estimated by fitting a simple  $pH_{min}$ -model (AEM, 63, 2355-2360, 1997).  $pH_{min}$ -values decreased from 5.0 at 5°C to 4.3 at 20°C and then increased to 4.7 at 37°C. These changes in  $pH_{min}$ -values has major influence on predictions from CPM-*Lm*, particularly for products with low pH values of less than about 5 and a new  $pH_{min}$ -model to describe the influence of temperature on  $pH_{min}$ -values in CPM-*Lm* was developed as shown below.

$$0^{\circ}\text{C} \leq T < T_{ref} \quad pH_{minT} = pH_{min0} - T * \left( \frac{pH_{min0} - pH_{minR}}{T_{ref}} \right)$$

$$T_{ref} < T < 37^{\circ}\text{C} \quad pH_{minT} = pH_{minR} + (T - T_{ref}) * \left( \frac{pH_{min37^{\circ}\text{C}} - pH_{minR}}{37 - T_{ref}} \right)$$

where  $T$  is the storage temperature (°C);  $pH_{minT}$  the fitted  $pH_{min}$ -value at  $T^{\circ}\text{C}$ ;  $T_{ref}$  the estimated reference temperature (°C);  $pH_{min0}$  and  $pH_{minR}$  the fitted  $pH_{min}$ -values at 0°C and  $T_{ref}$ (°C), respectively.

The fixed  $pH_{min}$ -value from an existing CPM-*Lm* including 12 environmental parameters (IJFM, 141, 137-150, 2010) was substituted by the new  $pH_{min}$ -model and the model performance has been evaluated for 33 growth/no growth responses of *L. monocytogenes* in a well characterized food with pH below 5.

Average bias and accuracy factor values were 1.16 and 1.27 for 30 growth curves at constant temperatures. The new  $pH_{min}$ -model can estimate the  $pH_{min}$ -value for *L. monocytogenes* based on temperature storage conditions and this markedly extend the limit of applicability of the existing CPM-*Lm* from pH 5.6 to pH 4.4.