A meta-regression model of the growth rate of *Listeria monocytogenes* as affected by temperature

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Introduction

The presence of *L. monocytogenes* in naturally-contaminated foods, its ability to endure various environmental stresses and grow at low temperatures and during the shelf-life of some foods are great challenges for the food industry.

To overcome this issue, **predictive models** can be used to evaluate if the process or the formulation of a food product allow the pathogen's inactivation or reduction to an acceptable level or prevents its outgrowth during shelf life.

In this sense, **Cardinal Parameters Models (CPM)** have been widely used to describe the **effect of environmental factors on microbial growth rates** (Fig. 1). To be used, the determination of the parameters (the **cardinal values**), is needed.

To account for strain variability while reducing the experimental work to be performed at the lab, **it is proposed here that meta-analysis of literature data could be useful to perform such assessments**. This statistical approach provides an enlarged vision about the research outcomes of a specific topic by examining a vast number of studies and integrating and interpreting their results.

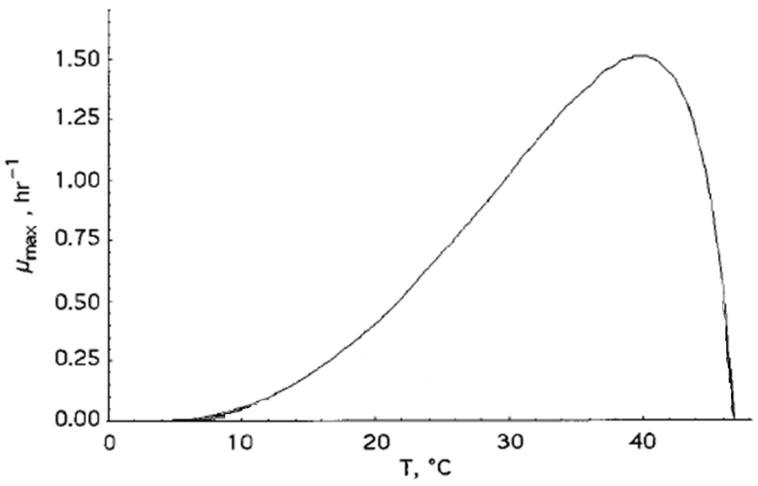

Fig. 1 – Classical Cardinal Parameter Model for temperature (adapted from Rosso et al., 1995).

Methodology

- **Literature search** was conducted in Web of Science, PubMed, Scopus and Google Scholar. Growth rate data from ComBase and the Nestlé Challenge Test Database were also collected.
- Following **study quality checking**, the square-roots of the growth rates considered appropriate for inclusion were fitted by nonlinear regression to the **cardinal model of Rosso without interactions** (Rosso et al., 1995).
- To **evaluate temperature's effect on growth rates** and **estimate comprehensive cardinal values**, meta-analysis was performed on a set of growth rates assessed at **optimal conditions of pH** [6.50; 8.00] **and a_w** [0.98; 1.00].
- Other sets of growth rates estimated using (i) **distinct reading methods**, (ii) **distinct broth types** and (iii) s**ub-optimal pH and a_w conditions** were created to appraise the share of the possible sources of variability by multilevel meta-analysis.
- Meta-analyses models and plots were built in R Studio version 1.0.136.

Results

- The set of growth rates assessed at optimal conditions of pH and a_w as a function of temperature (n=1004) retrieved from literature and the fitting of the CPM is shown in Fig. 2.

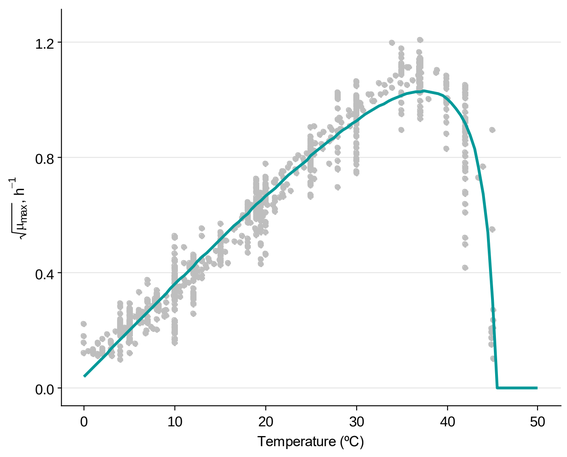

Fig. 2 – Fitting of the CPM to the optimal set of growth rates.

- The pooled parameters from the optimal set are presented in Table 1. The obtained S^2 and accuracy factor (0.01 and 1.00, respectively) indicate that a **good agreement between literature data and the predictions** was achieved, meaning that the fitted model is accurate.
- Regarding the possible sources of variability, it was concluded that **the reading method** (R^2=24.8%) **and the broth type** (R^2=60.1%) used to estimate growth rates largely **affect the estimation of cardinal values**. The pooled parameters from those subsets are shown in Table 1.
- It was concluded that **data at sub-optimal conditions**, especially in food products, were **inadequate to assess cardinal values**, as mean estimates changed and standard errors increased.
- The results also highlighted the **influence of pH and a_w values on the estimation of μ_{opt},** as expected, since optimal growth rates can vary depending on the environmental conditions of the medium on which growth is assessed.

Table 1 – Estimated cardinal values for the optimal set and for the distinct reading methods subsets

Set	T_{min} / °C	T_{opt} / °C	T_{max} / °C	μ_{opt} / h^{-1}
Optimal	-1.15 ± 2.43	37.42 ± 2.00	45.20 ± 0.37	1.06 ± 0.13
Optimal: OD reading method	-0.98 ± 4.28	37.27 ± 2.35	43.94 ± 2.16	1.12 ± 0.19
Optimal: CFU reading method	-2.08 ± 3.63	39.40 ± 6.25	44.66 ± 3.74	1.15 ± 0.52

Conclusions

- **Literature can be useful to assess CPM parameters** and to **provide an insight on sources of variability**, thus reducing the human efforts associated with experimental estimation of cardinal values .

References

- Rosso, L., Lobry, J.R., Bajard, S., Flandrois, J.P., 1995. Convenient model to describe the combined effects of temperature and pH on microbial growth. Appl. Environ. Microbiol. 61(2):610–616.