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Advanced Quantitative Microbiology for Foods and Biosystems

Models for Predicting Growth and Inactivation

Micha Peleg

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Dedication

In memory of my late parents and brother, and to my family, friends, teachers, and students, from all of whom I have received so much.

Preface

> A theory is believed by no one except the person who created it. Experimental results are believed by everyone except the person who got them.
>
> **Harlow Shapely**

Predictive, or perhaps more accurately, quantitative microbiology has been an active field of research in recent years. Numerous papers have been written on the subject, as well as many review articles and book chapters. A large amount of tabulated quantitative data and simulated growth and survival curves can now be downloaded from Websites, notably those posted by the USDA–ERRC (Eastern Regional Research Center) in the United States and IFR (Institute of Food Research) in the United Kingdom. Also posted on the Web are long lists of references that have dozens and sometimes hundreds of entries. Most recently, Robin C. McKellar and Xuewen Lu have edited *Modeling Microbial Responses in Foods* (CRC Press, 2003) — an update to the classic *Predictive Microbiology* by Tom. A. McMeekin, June N. Olley, Thomas Ross, and David A. Ratkowsky (John Wiley & Sons, 1983, 1993). Together with numerous other publications, they provide existing comprehensive coverage of the mathematical properties of the various existing quantitative models of microbial growth and inactivation, their origins and development during the years, and their application to specific organisms of interest in food and water safety or in disease control or eradication.

A large number of the publications in the food literature addresses the statistical aspects of a model derivation from experimental data, complementing the statistics textbooks that deal with sampling, data analysis, regression, distributions, quality control charts, and the like. Therefore, the purpose this book, by an author who is neither a practicing food or water microbiologist nor a statistician, is certainly not to add another compilation of inactivation and growth models and data or to provide an updated references list. The book is also not intended to discuss the strictly statistical aspects of mathematical models derivation and curve fitting. Discussion of these, as already stated, are readily available to the reader in many convenient forms.

The reason for writing this book is the feeling that research in the field of quantitative microbiology, especially of foods but also of other biosystems, needs new directions. In most scientific disciplines reaching maturity in which a massive body of literature exists, certain thought patterns become so ingrained that the foundations of the prevalent concepts, theories, and models are rarely questioned. A main objective of this book is to do just this — that is, to re-examine and challenge some of the dogmatic concepts that have dominated the field of quantitative microbiology for many years.

Another objective is to offer an alternative approach to modeling certain aspects of microbial growth and inactivation. The discussion will primarily focus on the *mathematical forms* of the proposed alternative models and on the rationale of their introduction as substitutes to those currently in use. Only when it is absolutely necessary will reference to biological aspects of the modeled phenomena be made. The mechanisms of microbial cell division and death and of spore formation, germination, and inactivation have been studied in great detail by professional microbiologists and other scientists. They should not concern us here, except when they have a quantitative manifestation and/or affect the shape of a growth or survival curve.

It is well known that different experimental procedures to grow, isolate, and count microorganisms can yield somewhat different results. Still, the published microbial count records to be analyzed and interpreted in this volume will be always considered as correctly determined and faithful representatives of the systems in question. The roles of sampling and uncertainties, for example, even when pertinent to the data interpretation, will only be assessed in terms of their possible effect on the mathematical model's structure and the magnitude of its parameters. The reliability of the reported experimental data is an issue that has been intentionally left out.

This book is primarily a summary of microbial modeling work done at the Department of Food Science of the University of Massachusetts Amherst in the last 10 years. Many individuals participated in the concept and model development and we have been helped in various ways by experts from outside the department. Several food companies and other institutions helped us considerably by allowing us to share records and, in one case, to create new data. Their contributions, without which this book could have never been written, are gratefully acknowledged.

We have been fortunate to be provided not only with challenging data but also with crucial mathematical ideas and technical assistance in programming. In writing this volume, no attempt has been made to offer an updated comprehensive list of pertinent works published by others and an assessment of their merits. Long lists of related publications can now be found easily in books and reviews, as well as in various sites on the Internet. Unfortunately, very few of these sources of information contain critical assessment of the cited publications even though, at least in some cases, they have obvious shortcomings. Whenever we deal with the publications of others, the emphasis will be primarily on the mathematical properties of the models that they present or propose. Only rarely will their data quality be addressed. Also, and as already stated, we have not tried to document the historical roots of published models and thus credit to the original authors might not have been given. For these omissions, I take full responsibility and apologize in advance to everyone whose work might not have received the proper acknowledgment that it deserves.

Many if not all of the concepts presented and discussed in this book's chapters will probably be controversial and even objectionable to some. This is quite understandable. In fact, although most of the ideas presented have been welcomed in mathematically oriented biological, food, and engineering publications, some were initially turned down by leading food and general microbiology journals for reasons that are still hard to understand. That the rejection came from expert referees demonstrates that a critical re-evaluation of the field's foundations is necessary and timely.

Comments made in several reviews have raised doubts about the openness of the field to any criticism of its long-held beliefs. The same can be said about the current attitude of certain governmental programs that fund food safety research. The verdicts of their review panels and administrators explicitly stated that revision of the currently held concepts of microbial inactivation, although acknowledged to be deficient, is not a welcome proposition, let alone a research priority. This attitude may be changing now and it is possible that this change is partly due to issues raised in the publications on which the first part of this book is based.

A growing circle of microbiologists and scientists in industry, academia, and government share our concerns about the quantitative models and calculation methods now in use in the food industry. Some have actively encouraged us to search for new models and to develop our nontraditional approach. This book will present growth, inactivation, and fluctuation models based on a departure from many of the established concepts in the field. Because the models that we propose are now available to professionals and students together in a single volume rather than scattered in many journals, they might invite criticism as well as trigger a debate on whether some of the theories that currently dominate the field of quantitative microbiology should be replaced.

It is to be hoped that the debate will result in the abandonment of some old ideas and open the way to novel and more effective solutions to the outstanding problems of predicting microbial growth and inactivation. Even if initiating such a debate is all that this book will ever achieve, the effort invested in writing it would be worthwhile. Still, I hope that some readers will discover the utility of the proposed approach and find that at least some of the models described here can be useful to their work. I also hope that the models originally developed for food and water will find applications in other fields, notably in environmental, pharmaceutical, and perhaps even clinical medical microbiology.

Acknowledgments

This book would have never seen the light and the studies on which it is based never come to fruition without the contributions and assistance of many individuals and several institutions. The help came in many forms: suggested key ideas, solutions to mathematical problems, programming, sharing or producing essential experimental data, computer simulations and graphing, and patient typing and retyping of the many drafts of the book's chapters and of the original journal articles summarized in them. During the years in which the research was done, we received much encouragement from friends and colleagues in other institutions. Although they did not participate directly in any of the projects, their moral support was invaluable to us, especially at times when some of our ideas have received an irrationally hostile response in certain quarters. At the same time, we have always appreciated the sympathetic and constructive comments of several anonymous referees and lament, of course, that we cannot thank them in person.

The first part of the book (Chapter 1 through Chapter 8) summarizes the results of research that, by and large, has never been funded, except for modest internal support from the Massachusetts Agricultural Experiment Station at Amherst. We have benefited greatly from a project funded by Nabisco (now Kraft); although it did not support us directly, it allowed us to participate in some of the experiments and gave us access to crucial data that we could not obtain from other sources. We have also been allowed to take a modest part in projects sponsored by Unilever, which also gave us access to helpful data and boosted our morale at the time.

Much of the second part of the book (Chapter 9 through Chapter 12) reports the results of work funded by the USDA–NRICGP (National Research Initiative Competitive Grants Program). (The project was approved when the program had been under a previous management, before a concept development could be labeled "passive research.") We gratefully acknowledge this old program's support.

The list of individuals and institutions to whom I am indebted is long and I wonder if it will ever be complete. It includes principal collaborators Joseph Horowitz, Claude Penchina, programmer Mark Normand, and Maria Corradini, who produced many of the figures that appear in this book. It also includes Martin Cole, Amos Nussinovitch, Osvaldo Campanella, Ora Hadas, and former graduate students Robert Engel and Karen Mattick, who have made significant direct contributions to our