ENCYCLOPEDIA OF
MICROBIOLOGY
VOLUME 2 D-L

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ACADEMIC PRESS, INC.
525 B Street, Suite 1900
San Diego, California 92101-4495

United Kingdom Edition published by
Academic Press Limited
24–28 Oval Road, London NW1 7DX

Library of Congress Cataloging-in-Publication Data

Encyclopedia of microbiology / edited by Joshua Lederberg
p. cm.
Includes bibliographical references and indexes.
ISBN 0-12-226891-1 (v. 1). -- ISBN 0-12-226892-X (v. 2). -- ISBN 0-12-226893-8 (v. 3). -- ISBN 0-12-226894-6 (v. 4)
1. Microbiology--Encyclopedias. I. Lederberg, Joshua.
QR9E53 1992
576'.03--dc20 92-4429
CIP

PRINTED IN THE UNITED STATES OF AMERICA

94 95 96 97 EB 9 8 7 6 5 4 3

ENCYCLOPEDIA OF

Microbiology

Volume 2 D–L

Editorial Advisory Board

Preface

For the purposes of this encyclopedia, microbiology has been understood to embrace the study of "microorganisms," including the basic science and the roles of these organisms in practical arts (agriculture and technology) and in disease (public health and medicine). Microorganisms do not constitute a well-defined taxonomic group; they include the two kingdoms of Archaebacteria and Eubacteria, as well as protozoa and those fungi and algae that are predominantly unicellular in their habit. Viruses are also an important constituent, albeit they are not quite "organisms." Whether to include the mitochondria and chloroplasts of higher eukaryotes is a matter of choice, since these organelles are believed to be descended from free-living bacteria. Cell biology is practiced extensively with tissue cells in culture, where the cells are manipulated very much as though they were autonomous microbes; however, we shall exclude this branch of research. Microbiology also is enmeshed thoroughly with biotechnology, biochemistry, and genetics, since microbes are the canonical substrates for many investigations of genes, enzymes, and metabolic pathways, as well as the technical vehicles for discovery and manufacture of new biological products, for example, recombinant human insulin.

Within these arbitrarily designated limits, let us consider the overall volume of published literature in microbiology, where to find its core, and strategies for searching for current information on particular topics. Most of the data for this preface are derived from the 1988 Journal Citation Reports Current Contents (T) of the Institute for Scientific Information (ISI). Table I lists the 53 most consequential journals in microbiology, assessed by citation impact factor, the average number of literature citations per article published in a given journal. Table II presents that list sorted by the total number of articles printed in each journal in 1988. Table III shows the distribution of journals citing the *Journal of Bacteriology* and the distribution of journals cited in it.

Obviously, the publications of the American Society for Microbiology (indicated by AMS in the tables) play a commanding role. The society is now making its journals available in electronically searchable form (on optical disks), which will greatly facilitate locating and retrieving the most up-to-date information on any given subject. In addition, interdisciplinary journals such as *Nature (London), Science*, and the *Proceedings of the National Academy of Sciences, U.S.A.* are important sources of prompt news of scientific developments in microbiology. It is difficult to assess how much of their total publication addresses microbiology. As seen in Table III, the bibliographies in the *Journal of Bacteriology* cite half as many articles from the *Proceedings* (2348) as from the *Journal of Bacteriology* itself (5708). The 7038 articles indicated in Table II probably reach some 10,000 per year when these interdisciplinary and other dispersed sources are taken into account. An equal number might be added from overlapping aspects of molecular biology and genetics. To find and read all these titles would tax any scholar, although it could be done as a near full-time occupation with the help of the weekly Current Contents (T) of the ISI. To start afresh, with perhaps a decade's accumulation of timely background, would be beyond reasonable human competence. No one person would intelligently peruse more than a small fraction of the total texts.

The "Encyclopedia of Microbiology" is intended to survey the entire field coherently, complementing material that would be included in an advanced undergraduate and graduate major course of university study. Particular topics should be accessible to talented high school and college students, as well as graduates involved in teaching, research, and technical practice of microbiology.

Even these hefty volumes cannot embrace all current knowledge in the field. Each article does provide key references to the literature available at the time of writing. Acquisition of more detailed and up-to-date knowledge depends on (1) exploiting the review and monographic literature and (2) bibliographic retrieval of the preceding and current research literature. To make greatest use of review literature and monographs, the journals listed in Table II are invaluable. Titles such as *Annual Reviews* should not be misunderstood: these journals appear at annual intervals, but 5 or 10 years of accumulated research is necessary for the inclusion of a focused treatment of a given subject.

To access bibliographic materials in microbiology, the main retrieval resources are Medline, sponsored by the U.S. National Library of Medicine, and the Science Citation Index of the ISI. With governmental subsidy, Medline is widely available at modest cost: terminals are available at every medical school and at many other academic centers. Medline provides searches of the recent literature by author, title, and key word, and offers on-line displays of the relevant bibliographies and abstracts. Medical aspects of microbiology are covered exhaustively; general microbiology is covered in reasonable depth. The Science Citation Index must recover its costs from user fees, but is widely available at major research centers. It offers additional search capabilities, especially by citation linkage. Therefore, starting with the bibliography of a given encyclopedia article, one can quickly find (1) all articles more recently published that have cited those bibliographic reference starting points and (2) all other recent articles that share bibliographic information with the others. With luck, one of these articles may be identified as another comprehensive review that has digested more recent or broader primary material.

On a weekly basis, services such as Current Contents on Diskette (ISI) and Reference Update offer still more timely access to current literature as well as abstracts with a variety of useful features. Under the impetus of intense competition, these services are evolving rapidly, to the great benefit of a user community desperate for electronic assistance in coping with the rapidly growing and intertwined networks of discovery. The bibliographic services of Chemical Abstracts and Biological Abstracts would also be potentially invaluable; however, their coverage of microbiology is rather limited.

In addition, major monographs have appeared from time to time—"The Bacteria," "The Prokaryotes," and many others. Your local reference library should be consulted for these volumes.

Valuable collections of reviews also include *Critical Reviews for Microbiology*, *Symposia of the Society for General Microbiology*, *Monographs of the ASM*, and *Proceedings of the International Congresses of Microbiology*.

The articles in this encyclopedia are intended to be accessible to a broader audience, not to take the place of review articles with comprehensive bibliographies. Citations should be sufficient to give the reader access to the latter, as may be required. We do apologize to many individuals whose contributions to the growth of microbiology could not be adequately embraced by the secondary bibliographies included here.

The organization of encyclopedic knowledge is a daunting task in any discipline; it is all the more complex in such a diversified and rapidly moving domain as microbiology. The best way to anticipate the rapid further growth that we can expect in the near future is unclear. Perhaps more specialized series in subfields of microbiology would be more appropriate. The publishers and editors would welcome readers' comments on these points, as well as on any deficiencies that may be perceived in the current effort.

My personal thanks are extended to Kathryn Linenger at Academic Press for her diligent, patient, and professional work in overseeing this series; to my coeditors, Martin Alexander, David A. Hopwood, Barbara H. Iglewski, and Allan I. Laskin; above all, to the many very busy scientists who took time to draft and review each of these articles.

Joshua Lederberg

Table I The Top Journals in Microbiology Listed by Impact Factor

Citation impact rank	Journal title	Number of articles published in 1988	Citation impact rank	Journal title	Number of articles published in 1988
1	*Microbiol. Rev.*	28	28	*FEMS Microbiol. Lett.*	365
2	*Adv. Microb. Ecol.*	10	29	*Am. J. Reprod. Immunol.*	50
3	*Annu. Rev. Microbiol.*	29	30	*Infection*	103
4	*FEMS Microbiol. Rev.*	13	31	*Can. J. Microbiol.*	236
5	*Yeast*	NA	32	*Curr. Microbiol.*	87
6	*J. Bacteriol.*	915	33	*J. Appl. Bacteriol.*	125
7	*Mol. Microbiol.*	94	34	*J. Microbiol. Meth.*	34
8	*Antimicrob. Agents Ch.*	408	35	*B. I. Pasteur*	20
9	*Rev. Infect. Dis.*	213	36	*ZBL Bakt. Mikr. Hyg. A*	164
10	*CRC Crit. Rev. Microbiol.*	12	37	*Ann. Inst. Pasteur Mic.*	58
11	*Syst. Appl. Microbiol.*	52	38	*Vet. Microbiol.*	104
12	*Int. J. Syst. Bacteriol.*	83	39	*Acta Path. Micro. Im. B*	NA
13	*J. Antimicrob. Chemoth.*	352	40	*Protistologica*	NA
14	*Appl. Environ. Microb.*	588	41	*Med. Microbiol. Immun.*	37
15	*J. Clin. Microbiol.*	619	42	*Diagn. Micr. Infec. Dis.*	60
16	*Adv. Appl. Microbiol.*	8	43	*Int. J. Food Microbiol.*	66
17	*Curr. Top. Microbiol.*	53	44	*J. Gen. Appl. Microbiol.*	27
18	*Arch. Microbiol.*	173	45	*Microbiol. Immunol.*	122
19	*J. Gen. Microbiol.*	367	46	*Lett. Appl. Microbiol.*	81
20	*Enzyme Microb. Tech.*	108	47	*Gen. Physiol. Biophys.*	57
21	*Eur. J. Clin. Microbiol.*	161	48	*A. Van Leeuw. J. Microb.*	51
22	*FEMS Microbiol. Ecol.*	42	49	*Symbiosis*	14
23	*J. Med. Microbiol.*	124	50	*Comp. Immunol. Microb.*	27
24	*J. Infection*	68	51	*Microbios.*	61
25	*Eur. J. Protistol.*	37	52	*ZBL Bakt. Mikr. Hyg. B*	76
26	*Microbiol. Sci.*	70	53	*J. Basic Microb.*	69
27	*Appl. Microbiol. Biot.*	270			

NA, Not available.

Table II Microbiology Journals Listed by Total Number of Articles Published per Year (1988)

Journal title	Number of articles published in 1988	Journal title	Number of articles published in 1988
J. Bacteriol.	915	*Int. J. Food Microbiol.*	66
J. Clin. Microbiol.	619	*Microbios.*	61
Appl. Environ. Microb.	588	*Diagn. Micr. Infec. Dis.*	60
Antimicrob. Agents Ch.	408	*Ann. Inst. Pasteur Mic.*	58
J. Gen. Microbiol.	367	*Gen. Physiol. Biophys.*	57
FEMS Microbiol. Lett.	365	*Curr. Top. Microbiol.*	53
J. Antimicrob. Chemoth.	352	*Syst. Appl. Microbiol.*	52
Appl. Microbiol. Biot.	270	*A. Van Leeuw. J. Microb.*	51
ZBL Bakt. Mikr. Hyg. A	240	*Am. J. Reprod. Immunol.*	50
Can. J. Microbiol.	236	*FEMS Microbiol. Ecol.*	42
Rev. Infect. Dis.	213	*Med. Microbiol. Immun.*	37
Arch. Microbiol.	173	*Eur. J. Protistol.*	37
Eur. J. Clin. Microbiol.	161	*J. Microbiol. Meth.*	34
J. Appl. Bacteriol.	125	*Eur. J. Protistology*	29
J. Med. Microbiol.	124	*Annu. Rev. Microbiol.*	29
Microbiol Immunol.	122	*Microbiol. Rev.*	28
Enzyme Microb. Tech.	108	*J. Gen. Appl. Microbiol.*	27
Vet. Microbiol.	104	*Comp. Immunol. Microb.*	27
Infection	103	*B. I. Pasteur*	20
Mol. Microbiol.	94	*Acta Path. Micro. Im.*	18
Curr. Microbiol.	87	*Symbiosis*	14
Int. J. Syst. Bacteriol.	83	*FEMS Microbiol. Rev.*	13
Lett. Appl. Microbiol.	81	*CRC Crit. R. Microbiol.*	12
Microbiol. Sci.	70	*Adv. Microb. Ecol.*	10
J. Basic Microb.	69	*Adv. Appl. Microbiol.*	8
		Total	7038

Table III.A Distribution of Journals Cited in *Journal of Bacteriology*, 1979–1988

Journal cited	Number of citations	Journal cited	Number of citations
J. Bacteriol.	5708	*Genetics*	183
P. Natl. Acad. Sci. U.S.A.	2348	*Can. J. Microbiol.*	139
J. Biol. Chem.	1698	*Arch. Biochem. Biophys.*	127
Mol. Gen. Genet.	1157	*Virology*	123
J. Mol. Biol.	1148	*Bacteriol. Rev.*	118
Gene	902	*Cold Spring Harb. Sym.*	110
Nature (London)	820	*Antimicrob. Agents Ch.*	109
Nucleic Acids Res.	804	*Escherichia Coli Sal.*	95
Cell	802	*Plant Physiol.*	80
J. Gen. Microbiol.	701	*J. Biochem.-Tokyo*	78
Infect. Immun.	478	*J. Virol.*	78
Methods Enzymol.	434	*Mol. Cell. Biol.*	68
Anal. Biochem.	411	*J. Infect. Dis.*	67
Biochim. Biophys. Acta	401	*Bio-Technol.*	61
Eur. J. Biochem.	376	*Exp. Gene Fusions*	60
Mol. Cloning Laboratory	363	*Trends Biochem. Sci.*	60
Microbiol. Rev.	361	*Mutat. Res.*	59
Arch. Microbiol.	347	*Syst. Appl. Microbiol.*	55
Embo J.	327	*Phytopathology*	51
Biochemistry-U.S.	310	*Adv. Bacterial Genet.*	50
Science	301	*Photochem. Photobiol.*	50
Appl. Environ. Microb.	294	*Biochimie*	49
FEMS Microbiol. Lett.	257	*J. Exp. Med.*	48
Exp. Mol. Genetics	234	*Agr. Biol. Chem. Tokyo*	47
Plasmid	234	*Int. J. Syst. Bacteriol.*	44
Biochem. Bioph. Res. Commun.	224	*FEMS Microbiol. Rev.*	43
FEBS Lett.	213	*J. Clin. Microbiol.*	42
Biochem. J.	207	*Curr. Microbiol.*	41
Annu. Rev. Microbiol.	194	*J. Cell Biol.*	41
Annu. Rev. Biochem.	188		
Annu. Rev. Genet.	187	All other (1301)	4311

(continues)

Table III.B *(continued)* Distribution of Journals Citing *Journal of Bacteriology*, 1979–1988

Journal citing	Number of citations	Journal citing	Number of citations
J. Bacteriol.	5708	*Curr. Genet.*	117
J. Biol. Chem.	1119	*FEMS Microbiol. Rev.*	115
J. Gen. Microbiol.	963	*J. Basic Microb.*	115
Mol. Gen. Genet.	896	*J. Antimicrob. Chemoth.*	112
Appl. Environ. Microb.	890	*Microb. Pathogenesis*	110
Microbiol. Rev.	759	*Science*	104
Infect. Immun.	663	*Ann. Inst. Pasteur Mic.*	101
FEMS Microbiol. Lett.	648	*Methods Enzymol.*	99
Gene	599	*ZBL Bakt. Mikr. Hyg. A*	98
P. Natl. Acad. Sci. U.S.A.	588	*A. Van Leeuw. J. Microb.*	95
Can. J. Microbiol.	579	*Annu. Rev. Biochem.*	94
Arch. Microbiol.	484	*Plant Physiol.*	88
Mol. Microbiol.	452	*J. Infect. Dis.*	86
J. Mol. Biol.	434	*J. Med. Microbiol.*	85
Nucleic Acids Res.	431	*Folia Microbiol.*	79
Biochim. Biophys. Acta	378	*Genetika*	79
Eur. J. Biochem.	350	*Gene Dev.*	78
Antimicrob. Agents Ch.	340	*Microbios.*	77
Annu. Rev. Microbiol.	316	*Arch. Biochem. Biophys.*	75
Cell	246	*Biotechnol. Bioeng.*	73
Biochimie	238	*Nature (London)*	69
Biochemistry-U.S.	236	*Syst. Appl. Microbiol.*	69
Plasmid	236	*Zh. Mikrob. Epid. Immun.*	67
Embo J.	234	*J. Antibiot.*	66
J. Clin. Microbiol.	214	*Annu. Rev. Genet.*	65
Genetics	201	*Microbiol. Immunol.*	65
Adv. Microb. Physiol.	199	*J. Biochem.-Tokyo*	64
Agr. Biol. Chem. Tokyo	198	*Microbial Ecol.*	60
Mol. Cell. Biol.	197	*Plant Soil*	58
CRC Crit. R. Microbiol.	194	*Anal. Biochem*	56
Curr. Microbiol	193	*Annu. Rev. Cell Biol.*	55
Appl. Microbiol. Biot.	183	*Biotechnol. Lett.*	54
J. Appl. Bacteriol.	169	*Adv. Microb. Ecol.*	53
Mutat. Res.	160	*Enzyme Microb. Tech.*	53
Biochem. Bioph. Res. Commun.	152	*Curr. Sci. India*	52
Rev. Infect. Dis.	141	*Eur. J. Clin. Microbiol.*	51
Biochem. J.	137	*J. Theor. Biol.*	51
Microbiol. Sci.	135	*Bot. Acta*	50
Int. J. Syst. Bacteriol.	128	*Photochem. Photobiol.*	50
FEBS Lett	125		

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How to Use the Encyclopedia

This encyclopedia is organized in a manner that we believe will be the most useful to you, and we would like to acquaint you with some of its features.

The volumes are organized alphabetically as you would expect to find them in, for example, magazine articles. Thus, "Foodborne Illness" is listed as such and would not be found under "Illness, Foodborne." If the first words in a title are not the primary subject matter contained in an article, the main subject of the title is listed first (e.g., "Heavy Metals, Bacterial Resistances," "Marine Habitats, Bacteria," "Method, Philosophy," "Transcription, Viral"). This is also true if the primary word of a title is too general (e.g.,"Bacteriocins, Molecular Biology"). Here, the word "bacteriocins" is listed first because "molecular biology" is a very broad topic. Titles are alphabetized letter-by-letter so that "Cell Membrane: Structure and Function" is followed by "Cellulases" and then by "Cell Walls of Bacteria."

Each article contains a brief introductory Glossary wherein terms that may be unfamiliar to you are defined *in the context of their use in the article*. Thus, a term may appear in another article defined in a slightly different manner or with a subtle pedagogic nuance that is specific to that particular article. For clarity, we have allowed these differences in definition to remain so that the terms are defined relative to the context of each article.

Articles about closely related subjects are identified in the Index of Related Titles at the end of the last volume (Volume 4). The article titles that are cross-referenced within each article may be found in this index, along with other articles on related topics.

The Subject Index contains specific, detailed information about any subject discussed in the *Encyclopedia*. Entries appear with the source volume number in boldface followed by a colon and the page number in that volume where the information occurs (e.g., "DNA repair by bacterial cells, **2**:9"). Each article is also indexed by its title (or a shortened version thereof), and the page ranges of the article appear in boldface (e.g. "Lyme disease, **2:639–646**" means that the primary coverage of the topic of Lyme disease occurs on pages 639–646 of Volume 2).

If a topic is covered primarily under one heading but additional related information may be found elsewhere, a cross-reference is given to the related material. For example, "Biodegradation" would contain all the page numbers where relevant information occurs, followed by "*See also* Bioremediation; Pesticide biodegradation" for different but related information. Similarly, a "*See*" reference refers the reader from a less-used synonym (or acronym) to a more specific or descriptive subject heading. For example, "Immunogens, synthetic. *See* Vaccines, synthetic." A *See under* cross-reference guides the reader to a specific subheading under a term. For example, "Mixis. *See under* Genome rearrangement."

An additional feature of the Subject Index is the identification of Glossary terms. These appear in the index where the word "defined" (or the words "definition of") follows an entry. As we noted earlier, there may be more than one definition for a particular term, and as when using a dictionary, you will be able to choose among several different usages to find the particular meaning that is specifically of interest to you.

Contents

D

Dairy Products

Mary Ellen Sanders
Consultant; Littleton, Colorado

Glossary

Bacteriophage Virus infecting a bacterium

Commercial sterility Processing (usually retort processing) of food to eliminate all pathogenic and spoilage microorganisms that can contribute to food spoilage under normal storage conditions. The only microbes, if any, remaining in a commercially sterile product are extremely heat-resistant bacterial spores, which can cause spoilage of product stored at unusually high storage temperatures

Fluid milk Milk that is prepared to be consumed as a natural liquid product, including raw or pasteurized milks with different milk fat contents or vitamin or milk solids fortifications

Lactic acid bacteria Name of a group of bacteria belonging to a diversity of genera used to effect food fermentations; its composed chiefly of bacteria whose primary metabolic end product from carbohydrate metabolism is lactic acid, although poor lactate producers (e.g., leuconostocs and propionibacteria) are sometimes included because of their association with food fermentations

Milk products Products manufactured from fluid milk, including natural cheeses, processed cheeses, fermented milks, yogurts, butter, ice cream, sour cream, whipped cream, canned milks, and dried milk

Starter culture Microbial strain or mixture of strains, species, or genera used to effect a fermentation and bring about functional changes in milk that lead to desirable characteristics in the fermented product

THE MICROBIOLOGY OF DAIRY PRODUCTS encompasses the safety and spoilage of fluid milk and milk products, as well as the fermentation of milk into a plethora of cheeses, yogurts, and fermented milks produced worldwide. These two facets of dairy microbiology are intricately associated, because undoubtedly, the first fermented milk products made some 8000 years ago provided a means for preserving milk as a safe and wholesome food. A diversity of microbes is associated with dairy products, including gram-positive and gram-negative bacteria, molds, yeasts, and bacteriophages. Spoilage and pathogenic microorganisms are predominantly controlled by pasteurization, refrigeration, fermentation, and limiting postprocesses contamination. Reduced water activity, high salt content, and heat sterilization also contribute to the preservation of some dairy products. Great effort is expended to control microbes responsible for spoilage or pathogenicity, but microbes are intentional additives to milk destined for fermentation. These microbes serve to preserve milk primarily through the production of organic acids. The dairy microbiologist must balance microbial populations and activities in milk so that positive effects are enhanced and spoilage and pathogenesis are discouraged or eliminated.

I. Natural Flora of Milk

Milk, as it is produced by the mammal, is sterile. Bacteria inhabiting the teat do, however, migrate up into the interior, causing even aseptically drawn milk to contain some bacteria, predominantly micrococci, streptococci, and *Corynebacterium bovis*. Milk taken from a mastitic animal (one with a teat or udder infection) will show dramatic levels of microbes, including streptococci, staphylococci, coliforms, *Pseudomonas aeruginosa*, and *Corynebacterium pyogenes*. Animals sick with other infections may also shed pathogenic microbes, including *Mycobacterium* species, *Brucella* species, mycoplasma, and *Coxiella burnetii*. Milk from a healthy animal does develop a complex flora on milking. Because milk is an animal product, microbes associated with mammals, farms, agricultural feedstuffs, and green plant material are often present in milk. Bacilli from the soil, clostridia from silage, coliforms from manure and bedding, and streptococci from green plant material commonly contaminate milk. In addition, the storage and processing environment and equipment, including milking machines, farm storage tanks, transportation equipment, cooling tanks, and milk processing equipment contribute greatly to the microbial flora of fluid milk.

II. Microbial Spoilage

A. Fluid Milk

The spoilage of fluid milk is dominated by the effects of pasteurization, which limits the presence of many microbes, and of refrigeration, which controls the growth of all but psychrotrophic microbes. Pasteurization processes for milk are designed to kill all microbes that are likely to contribute to disease from the consumption of milk. Along with the pathogens, yeasts, molds, and gram-negative and many gram-positive microbes are killed, greatly contributing not only to the safety, but the microbial stability of milk during storage. Because thermoduric and thermophilic microbes can survive pasteurization and to ensure processors that the minimum heating is achieved, processors often use temperatures and times somewhat beyond what is minimally required.

The greatest challenge to fluid milk processors is to limit the contamination that occurs after pasteurization during transport and bottling of milk. The extent of this postprocess contamination is directly related to the level of sanitation in the processing plant and suitable refrigeration.

By far, the most significant group of microbes in the spoilage of fluid milk is the psychrotrophs. Psychrotrophs are microorganisms that are capable of growing at refrigeration temperatures, although their *optimum* growth temperature may be much higher. Psychrotrophs include species from at least 27 genera of bacteria, four genera of yeast, and four genera of molds (Table I). Proper refrigeration is of the utmost importance to the control of microbial growth, because a small increase in storage temperature can result in a large decrease in bacterial generation times. [*See* REFRIGERATED FOODS.]

B. Cheese

The final composition of cheese relative to moisture content, salt content, fat content, and pH can vary tremendously in different varieties. Because all these factors contribute to the microbial stability of cheese, the only general statement about microbial stability that can be made is that cheeses are more stable than the milk from which they were made. Moisture content can range from 80% in cottage and cream cheeses down to 35% in hard, grating cheeses. Salt ranges from 1.5 to 5%, although a more significant effect on water activity than expected is seen because the salt is concentrated in the aqueous phase. Final titratable acidities during fermentation may also vary; however, a substandard fermentation risks both rapid spoilage and health hazards.

Molds, yeasts, and anaerobic sporeformers are involved most often in the spoilage of cheese, although a diversity of psychrotrophic microbes can spoil high-moisture cheeses, such as cottage cheese. Molds cause an unsightly appearance to cheese surfaces and can pose a health threat (see Section III). Anaerobic sporeformers such as clostridia, coliforms, and even unbalanced levels of gas-producing starter strains can cause abnormal gas formation. Spoilage during ripening of cheese can be controlled by maintaing low ripening temperatures and low humidity, factors that may inhibit microbial or enzymatic ripening processes. Sporeformers have been successfully controlled using nisin, an antibiotic produced by *Lactococcus lactis* subsp. *lactis*, or with the enzyme lysozyme.

Table I Genera of Bacteria, Yeasts, and Molds Containing Psychrotrophic Species

Bacteria	Yeasts	Molds
Acinetobacter	*Candida*	*Aspergillus*
Aeromonas	*Cryptococcus*	*Cladosporium*
Alcaligenes	*Rhodotorula*	*Penicillium*
Arthrobacter	*Torulopsis*	*Trichothecium*
Bacillus		
Chromobacterium		
Citrobacter		
Clostridium		
Corynebacterium		
Enterobacter		
Erwinia		
Escherichia		
Flavobacterium		
Klebsiella		
Lactobacillus		
Leuconostoc		
Listeria		
Microbacterium		
Micrococcus		
Moraxella		
Proteus		
Pseudomonas		
Serratia		
Streptomyces		
Streptococcus		
Vibrio		
Yersinia		

[Adapted from International Commission on Microbiological Specifications for Foods (1980). "*Microbial Ecology of Foods*," Vol. 1, p. 5. Academic Press, New York.]

C. Fermented Milks

Microbial growth is controlled in fermented milks by the low pH and high titratable acidity achieved during fermentation as well as dominance of the flora by starter bacteria. The lactic cultures can lower the pH to 4.8 and lower, depending on the product, and the pH may continue to drop during refrigerated storage. At this level of acidity, pathogens are effectively inhibited and even killed on storage. Spoilage is limited to yeasts and molds, which may accompany addition of flavorings and fruits that may be added to the product. As long as acid production is not inhibited during fermentation, a safe and long-shelf-life product results.

D. Dried Milk Products

Dried milks products, often prepared for use as ingredients in other foods, include whole milk, skim milk, whey, buttermilk, cheese, and cream. The drying process, although conducted at elevated temperatures, cannot be relied on as a method of microbial destruction. Proper pasteurization, sanitation, and product handling are the only consistent controls over the safety of these products. Once dried, these products are microbiologically stable. However, any remaining pathogens could be a threat in food subsequently formulated with the contaminated ingredient.

E. Canned Milks

Canned evaporated milk is heated to achieve commercial sterility. Therefore, all pathogens are destroyed, although some extremely heat-resistant spores such as *Bacillus stearothermophilus* might survive. This product is both shelf-stable under normal storage temperatures and pathogen-free. Sweetened condensed milks rely on pasteurization, low water activity, and high sugar content for preservation. These products are not heat processed after can closing and therefore can spoil from molds or yeast that enter during the filling operation or through can defects. Another class of commercially sterile milks has been developed. These undergo high-temperature–short-time sterilization and are aseptically packaged in special paper containers. These products are stable at room temperature.

F. Ice Cream Mixes

These mixes are formulated with milk, cream, sugar, emulsifiers and stabilizers, colors, fruits, nuts, and flavorings. Therefore, the microbial content of these mixes can be diverse, depending on the content of the respective ingredients. Although the final product from these mixes is frozen and as such does not support microbial growth, treatment and formulation of the product before freezing can result in spoilage and safety concerns. Procurement of ingredients of good microbial quality, proper pasteurization, careful postpasteurization handling, and refrigeration prevent microbial problems. Adherence to government regulations on bacterial counts for these products help assure Good Manufacturing Practices. [*See* FOODS, QUALITY CONTROL.]