Innovations in Agricultural
& Biological Engineering

The Chemistry of Milk and Milk Products

Physicochemical Properties, Therapeutic Characteristics, and Processing Methods

Editors
Megh R. Goyal | Suvartan Ranvir
Junaid Ahmad Malik

CRC Press
Taylor & Francis Group
APPLE ACADEMIC PRESS

THE CHEMISTRY OF MILK AND MILK PRODUCTS

Physicochemical Properties, Therapeutic Characteristics, and Processing Methods

Innovations in Agricultural and Biological Engineering

THE CHEMISTRY OF MILK AND MILK PRODUCTS

Physicochemical Properties,
Therapeutic Characteristics, and Processing Methods

Edited by

Megh R. Goyal, PhD, PE
Suvartan Ranvir, PhD
Junaid Ahmad Malik, PhD

AAP | APPLE ACADEMIC PRESS

First edition published 2024

Apple Academic Press Inc.
1265 Goldenrod Circle, NE,
Palm Bay, FL 32905 USA

760 Laurentian Drive, Unit 19,
Burlington, ON L7N 0A4, CANADA

CRC Press
6000 Broken Sound Parkway NW,
Suite 300, Boca Raton, FL 33487-2742 USA

4 Park Square, Milton Park,
Abingdon, Oxon, OX14 4RN UK

Apple Academic Press exclusively co-publishes with CRC Press, an imprint of Taylor & Francis Group, LLC

Library and Archives Canada Cataloguing in Publication

Title: The chemistry of milk and milk products : physicochemical properties, therapeutic characteristics, and processing methods / edited by Megh R. Goyal, PhD, PE, Suvartan Ranvir, PhD, Junaid Ahmad Malik, PhD.
Names: Goyal, Megh R., editor. | Ranvir, Suvartan, editor. | Malik, Junaid Ahmad, 1987- editor.
Series: Innovations in agricultural and biological engineering.
Description: First edition. | Series statement: Innovations in agricultural and biological engineering | Includes bibliographical references and index.
Identifiers: Canadiana (print) 20230189555 | Canadiana (ebook) 20230189628 | ISBN 9781774912249 (hardcover) | ISBN 9781774912256 (softcover) | ISBN 9781003340706 (PDF)
Subjects: LCSH: Milk—Composition. | LCSH: Dairy products—Composition. | LCSH: Dairy processing. | LCSH: Milk—Health aspects. | LCSH: Dairy products—Health aspects. | LCSH: Agricultural chemistry.
Classification: LCC SF251 .C47 2023 | DDC 637—dc23

Library of Congress Cataloging-in-Publication Data

CIP data on file with US Library of Congress

ISBN: 978-1-77491-224-9 (hbk)
ISBN: 978-1-77491-225-6 (pbk)
ISBN: 978-1-00334-070-6 (ebk)

ABOUT THE BOOK SERIES: INNOVATIONS IN AGRICULTURAL AND BIOLOGICAL ENGINEERING

Under this book series, Apple Academic Press Inc. is publishing book volumes over a span of 8–10 years in the specialty areas defined by the American Society of Agricultural and Biological Engineers (<asabe.org>). Apple Academic Press Inc. aims to be a principal source of books in agricultural and biological engineering. We welcome book proposals from readers in areas of their expertise.

The mission of this series is to provide knowledge and techniques for agricultural and biological engineers (ABEs). The book series offers high-quality reference and academic content on agricultural and biological engineering (ABE) that is accessible to academicians, researchers, scientists, university faculty and university-level students, and professionals around the world.

Agricultural and biological engineers ensure that the world has the necessities of life, including safe and plentiful food, clean air and water, renewable fuel and energy, safe working conditions, and a healthy environment by employing knowledge and expertise of the sciences, both pure and applied, and engineering principles. Biological engineering applies engineering practices to problems and opportunities presented by living things and the natural environment in agriculture.

ABE embraces a variety of the following specialty areas (<asabe.org>): aquaculture engineering, biological engineering, energy, farm machinery and power engineering, food, and process engineering, forest engineering, information, and electrical technologies, soil, and water conservation engineering, natural resources engineering, nursery, and greenhouse engineering, safety, and health, and structures and environment.

For this book series, we welcome chapters on the following specialty areas (but not limited to):

- Academia to industry to end-user loop in agricultural engineering;
- Agricultural mechanization;
- Aquaculture engineering;
- Biological engineering in agriculture;

- Biotechnology applications in agricultural engineering;
- Energy source engineering;
- Farm to fork technologies in agriculture;
- Food and bioprocess engineering;
- Forest engineering;
- GPS and remote sensing potential in agricultural engineering;
- Hill land agriculture;
- Human factors in engineering;
- Impact of global warming and climatic change on agriculture economy;
- Information and electrical technologies;
- Irrigation and drainage engineering;
- Nanotechnology applications in agricultural engineering;
- Natural resources engineering;
- Nursery and greenhouse engineering;
- Potential of phytochemicals from agricultural and wild plants for human health;
- Power systems and machinery design;
- Robot engineering and drones in agriculture;
- Rural electrification;
- Sanitary engineering;
- Simulation and computer modeling;
- Smart engineering applications in agriculture;
- Soil and water engineering;
- Micro-irrigation engineering;
- Structures and environment engineering;
- Waste management and recycling;
- Any other focus areas.

For more information on this series, readers may contact:

Megh R. Goyal, PhD, PE
Book Series Senior Editor-in-Chief: Innovations in Agricultural and Biological Engineering

OTHER BOOKS ON AGRICULTURAL AND BIOLOGICAL ENGINEERING BY APPLE ACADEMIC PRESS, INC.

Management of Drip/Trickle or Micro Irrigation
Megh R. Goyal, PhD, PE, Senior Editor-in-Chief
Evapotranspiration: Principles and Applications for Water Management
Megh R. Goyal, PhD, PE and Eric W. Harmsen, PhD Editors

Book Series: Research Advances in Sustainable Micro Irrigation
Senior Editor-in-Chief: Megh R. Goyal, PhD, PE

- **Volume 1:** Sustainable Micro Irrigation: Principles and Practices
- **Volume 2:** Sustainable Practices in Surface and Subsurface Micro Irrigation
- **Volume 3:** Sustainable Micro Irrigation Management for Trees and Vines
- **Volume 4:** Management, Performance, and Applications of Micro Irrigation Systems
- **Volume 5:** Applications of Furrow and Micro Irrigation in Arid and Semi-Arid Regions
- **Volume 6:** Best Management Practices for Drip Irrigated Crops
- **Volume 7:** Closed Circuit Micro Irrigation Design: Theory and Applications
- **Volume 8:** Wastewater Management for Irrigation: Principles and Practices
- **Volume 9:** Water and Fertigation Management in Micro Irrigation
- **Volume 10:** Innovation in Micro Irrigation Technology

Book Series: Innovations and Challenges in Micro Irrigation
Senior Editor-in-Chief: Megh R. Goyal, PhD, PE

- Engineering Interventions in Sustainable Trickle Irrigation: Water Requirements, Uniformity, Fertigation, and Crop Performance
- Management Strategies for Water Use Efficiency and Micro Irrigated Crops: Principles, Practices, and Performance

- Micro-Irrigation Engineering for Horticultural Crops: Policy Options, Scheduling, and Design
- Micro-Irrigation Management: Technological Advances and Their Applications
- Micro-Irrigation Scheduling and Practices
- Performance Evaluation of Micro-Irrigation Management: Principles and Practices
- Potential of Solar Energy and Emerging Technologies in Sustainable Micro-Irrigation
- Principles and Management of Clogging in Micro-Irrigation
- Sustainable Micro-Irrigation Design Systems for Agricultural Crops: Methods and Practices

Book Series: Innovations in Agricultural and Biological Engineering
Senior Editor-in-Chief: Megh R. Goyal, PhD, PE

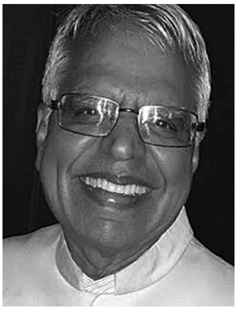
- Advanced Research Methods in Food Processing Technologies
- Advances in Food Process Engineering: Novel Processing, Preservation and Decontamination of Foods
- Advances in Green and Sustainable Nanomaterials: Applications in Energy, Biomedicine, Agriculture, and Environmental Science
- Advances in Sustainable Food Packaging Technology
- Analytical Methods for Milk and Milk Products, 2-volume set:
    - Volume 1: Sampling Methods, Chemical and Compositional Analysis
    - Volume 2: Physicochemical Analysis of Concentrated, Coagulated and Fermented Products
- Biological and Chemical Hazards in Food and Food Products: Prevention, Practices, and Management
- Bioremediation and Phytoremediation Technologies in Sustainable Soil Management, 4-volume set:
    - Volume 1: Fundamental Aspects and Contaminated Sites
    - Volume 2: Microbial Approaches and Recent Trends
    - Volume 3: Inventive Techniques, Research Methods, and Case Studies
    - Volume 4: Degradation of Pesticides and Polychlorinated Biphenyls
- Dairy Engineering: Advanced Technologies and Their Applications
- Developing Technologies in Food Science: Status, Applications, and Challenges

- Emerging Technologies in Agricultural Engineering
- Engineering Interventions in Agricultural Processing
- Engineering Interventions in Foods and Plants
- Engineering Practices for Agricultural Production and Water Conservation: An Interdisciplinary Approach
- Engineering Practices for Management of Soil Salinity: Agricultural, Physiological, and Adaptive Approaches
- Engineering Practices for Milk Products: Dairyceuticals, Novel Technologies, and Quality
- Enzyme Inactivation in Food Processing: Technologies, Materials, and Applications
- Field Practices for Wastewater Use in Agriculture: Future Trends and Use of Biological Systems
- Flood Assessment: Modeling and Parameterization
- Food Engineering: Emerging Issues, Modeling, and Applications
- Food Process Engineering: Emerging Trends in Research and Their Applications
- Food Processing and Preservation Technology: Advances, Methods, and Applications
- Food Technology: Applied Research and Production Techniques
- Functional Dairy Ingredients and Nutraceuticals: Physicochemical, Technological, and Therapeutic Aspects
- Handbook of Research on Food Processing and Preservation Technologies, 5-volume set:
    - Volume 1: Nonthermal and Innovative Food Processing Methods
    - Volume 2: Nonthermal Food Preservation and Novel Processing Strategies
    - Volume 3: Computer-Aided Food Processing and Quality Evaluation Techniques
    - Volume 4: Design and Development of Specific Foods, Packaging Systems, and Food Safety
    - Volume 5: Emerging Techniques for Food Processing, Quality, and Safety Assurance
- Modeling Methods and Practices in Soil and Water Engineering
- Nanotechnology and Nanomaterial Applications in Food, Health, and Biomedical Sciences
- Nanotechnology Applications in Agricultural and Bioprocess Engineering: Farm to Table

- Nanotechnology Applications in Dairy Science: Packaging, Processing, and Preservation
- Nanotechnology Horizons in Food Process Engineering, 3-volume set:
  - Volume 1: Food Preservation, Food Packaging and Sustainable Agriculture
  - Volume 2: Scope, Biomaterials, and Human Health
  - Volume 3: Trends, Nanomaterials, and Food Delivery
- Novel and Alternative Methods in Food Processing: Biotechnological, Physicochemical, and Mathematical Approaches
- Novel Dairy Processing Technologies: Techniques, Management, and Energy Conservation
- Novel Processing Methods for Plant-Based Health Foods: Extraction, Encapsulation and Health Benefits of Bioactive Compounds
- Novel Strategies to Improve Shelf-Life and Quality of Foods: Quality, Safety, and Health Aspects
- Phytochemicals and Medicinal Plants in Food Design: Strategies and Technologies for Improved Healthcare
- Processing of Fruits and Vegetables: From Farm to Fork
- Processing Technologies for Milk and Milk Products: Methods, Applications, and Energy Usage
- Quality Control in Fruit and Vegetable Processing: Methods and Strategies
- Scientific and Technical Terms in Bioengineering and Biological Engineering
- Soil and Water Engineering: Principles and Applications of Modeling
- Soil Salinity Management in Agriculture: Technological Advances and Applications
- State-of-the-Art Technologies in Food Science: Human Health, Emerging Issues and Specialty Topics
- Sustainable and Functional Foods from Plants
- Sustainable Biological Systems for Agriculture: Emerging Issues in Nanotechnology, Biofertilizers, Wastewater, and Farm Machines
- Sustainable Nanomaterials for Biomedical Engineering: Impacts, Challenges, and Future Prospects
- Sustainable Nanomaterials for Biosystems Engineering: Trends in Renewable Energy, Environment, and Agriculture
- Technological Interventions in Dairy Science: Innovative Approaches in Processing, Preservation, and Analysis of Milk Products

- Technological Interventions in Management of Irrigated Agriculture
- Technological Interventions in the Processing of Fruits and Vegetables
- Technological Processes for Marine Foods, From Water to Fork: Bioactive Compounds, Industrial Applications, and Genomics
- The Chemistry of Milk and Milk Products: Physicochemical Properties, Therapeutic Characteristics, and Processing Methods

ABOUT SENIOR-EDITOR-IN-CHIEF



Megh R. Goyal, PhD, PE

Retired Professor in Agricultural and Biomedical Engineering, University of Puerto Rico, Mayaguez Campus; Senior Acquisitions Editor, Biomedical Engineering and Agricultural Science, Apple Academic Press, Inc.

Megh R. Goyal, PhD, PE, is, currently a retired professor of agricultural and biomedical engineering from the General Engineering Department at the College of Engineering at the University of Puerto Rico–Mayaguez Campus (UPRM); and Senior Acquisitions Editor and Senior Technical Editor-in-Chief for Agricultural and Biomedical Engineering for Apple Academic Press Inc. During his professional career, he has worked as a Soil Conservation Inspector; Research Assistant at Haryana Agricultural University and Ohio State University; Research Agricultural Engineer/Professor at the Department of Agricultural Engineering of UPRM; and Professor of Agricultural and Biomedical Engineering in the General Engineering Department of UPRM. He spent a one-year sabbatical leave in 2002–2003 at the Biomedical Engineering Department of Florida International University, Miami, USA.

Dr. Goyal was the first agricultural engineer to receive the professional license in agricultural engineering from the College of Engineers and Surveyors of Puerto Rico. In 2005, he was proclaimed the "Father of Irrigation Engineering in Puerto Rico for the Twentieth Century" by the American Society of Agricultural and Biological Engineers, Puerto Rico Section, for his pioneering work on micro irrigation, evapotranspiration, agroclimatology, and soil and water engineering.

During his professional career of 52 years, he has received many awards, including Scientist of the Year, Membership Grand Prize for the American Society of Agricultural Engineers Campaign, Felix Castro Rodriguez Academic Excellence Award, Man of Drip Irrigation by the Mayor of Municipalities of Mayaguez/Caguas/Ponce and Senate/Secretary of Agriculture of ELA, Puerto Rico, and many others. He has been recognized as one of the experts "who rendered meritorious service for the development of [the] irrigation sector in India" by the Water Technology Centre of Tamil Nadu

Agricultural University in Coimbatore, India, and ASABE who bestowed on him the 2018 Netafim Microirrigation Award.

Dr. Goyal has authored more than 200 journal articles and edited more than 100 books. AAP has published many of his books, including *Management of Drip/Trickle or Micro Irrigation; Evapotranspiration: Principles and Applications for Water Management;* ten-volume set on *Research Advances in Sustainable Micro Irrigation.* He has also authored the textbooks *Elements of Agroclimatology* (Spanish) by UNISARC, Colombia, and two *Bibliographies on Drip Irrigation.* Dr. Goyal has also developed several book series with AAP, including Innovations in Agricultural & Biological Engineering (with over 60 titles in the series to date), Innovations and Challenges in Micro Irrigation; and Innovations in Plant Science for Better Health: From Soil to Fork.

Dr. Goyal received his BSc degree in Engineering from Punjab Agricultural University, Ludhiana, India, and his MSc and PhD degrees from the Ohio State University, Columbus, Ohio, USA. He also earned a Master of Divinity degree from the Puerto Rico Evangelical Seminary, Hato Rey, Puerto Rico, USA.

ABOUT THE COEDITORS

Suvartan G. Ranvir, PhD
Assistant Professor in Department of Dairy Chemistry, Warner College of Dairy Technology, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, Uttar Pradesh, India.

Suvartan Gautam Ranvir, PhD, is working as Assistant Professor in the Department of Dairy Chemistry at Warner College of Dairy Technology, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, Uttar Pradesh, India. Dr. Ranvir is currently working in ultra-high-temperature-treated milk (UHT), low glycemic index food, and extraction of micronutrients and their encapsulation in food. He has published several research papers in national and international journals, a competitive examination book on dairy science, book chapters, popular articles, conference papers, abstracts, and editorial opinions. He is advising several MTech scholars in Dairy Chemistry and has successfully guided five postgraduate students for their dissertation work. He also serves as an external examiner for various Indian state agricultural universities and as editor and reviewer for several journals. He also served as a senior executive in Mother Dairy Fruit and Private Limited, Delhi from 2013–2015. Dr. Ranvir has successfully completed ISO lead auditor and internal auditor certification. He is a life member of Association of Food Scientists & Technologists (AFSTI), India.

He holds a BTech (2011) degree in Dairy Technology from Maharashtra Animal and Fishery Sciences University (MAFSU) Nagpur, Maharashtra, India. He received his MTech (2013) and PhD (2019) degrees in Dairy Chemistry from ICAR-National Dairy Research Institute Karnal, Haryana, India. For his PhD research work, he has received best poster awards in national and international conferences four times. Also he has received a DuPont Nutri-Scholar Award, India (net cash prize 75000 Rs). He is a recipient of a Senior Research Fellowship (2015) from the Indian Council of Agricultural Research; Senior Research Fellowship from the Babasaheb Ambedkar Research and Training Institute; a Young Scientist Award (2020);

Young Research Achiever Award (2020); Indian Council of Agricultural Research-Senior Research-National Dairy Research Institute Fellowship for MTech and PhD programs.

Junaid Ahmad Malik, PhD
Lecturer, Department of Zoology,
Government Degree College, Bijbehara,
Kashmir, Jammu and Kashmir, India

Junaid Ahmad Malik, PhD, is a Lecturer with the Department of Zoology at Government Degree College, Bijbehara, Kashmir (J&K), India, and is actively involved with teaching and research activities. He has more than eight years of research experience. His areas of interest are ecology, soil macrofauna, wildlife biology, conservation biology, etc. Dr. Malik has published over 20 research articles and technical papers in international peer-reviewed journals and has authored and edited books, book chapters, and more than 10 popular editorial articles. He also serves as an editor and reviewer of several journals. He has participated in several state, national, and international conferences, seminars, workshops, and symposia and has more than 20 conference papers to his credit. He is a life member of the Society for Bioinformatics and Biological Sciences.

Dr. Malik received a BSc (2008) in Science from the University of Kashmir, Srinagar, J&K; MSc (2010) in Zoology from Barkatullah University, Bhopal, Madhya Pradesh, India; and PhD (2015) in Zoology from the same university. He completed his BEd program in 2017 at the University of Kashmir, Srinagar, J&K.

CONTENTS

CONTRIBUTORS

V. K. Ammu
Dairy Engineering Division, ICAR-National Dairy Research Institute, SRS Bengaluru, Adugodi, Karnataka, India

S. Athira
Department of Food Chemistry, College of Food Technology, Kerala Veterinary and Animal Sciences University, Thrissur, Kerala, India

Aarthy Bose
Department of Dairy Chemistry, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Allahabad, Uttar Pradesh, India

Mitul R. Bumbadiya
College of Dairy Science, Kamdhenu University, Amreli-Rajkot highway, Near Shedubhar Village, Amreli, Gujarat, India

Ramesh F. Chavan
Department of Chemical Technology, Dr. Babasaheb Ambedkar Marathwada University, Jaisingpura, Aurangabad, Maharashtra, India

Nandita Das
Dairy Chemistry Division, National Dairy Research Institute (NDRI), Karnal, Haryana, India

Partha Pratim Debnath
Faculty of Dairy Technology, West Bengal University of Animal and Fishery Sciences (WBUAFS), Mohanpur, Nadia, West Bengal, India

Gajanan P. Deshmukh
Dairy Engineering Department, SRS of ICAR-National Dairy Research Institute (NDRI), SRS, Bengaluru, Karnataka

Jyotika Dhankhar
Maharshi Dayanand University (MDU), Rohtak, Haryana, India

Chandni Dularia
Dairy Technology Division, National Dairy Research Institute (NDRI), Karnal, Haryana, India

Megh R. Goyal
Senior Technical Editor-in-Chief for Apple Academic Press; Retired Professor, University of Puerto Rico-Mayaguez, Mayaguez, Puerto Rico

Subrota Hati
SMC College of Dairy Science, Kamdhenu University, Anand, Gujarat, India

Ankita Hooda
Dairy Technology Division, National Dairy Research Institute (NDRI), Karnal, Haryana, India

Shamim Hossain
Dairy Technology Division, National Dairy Research Institute (NDRI), Karnal, Haryana

Thejus Jacob
Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Allahabad, Uttar Pradesh, India

Naveen Jose
Dairy Engineering Department, SRS of ICAR- National Dairy Research Institute (NDRI), SRS, Bengaluru, Karnataka, India

Drishti Kadian
Dairy Technology Division, National Dairy Research Institute (NDRI), Karnal, Haryana, India

Payal Karmakar
Dairy Chemistry Division, ICAR - National Dairy Research Institute, Karnal, Haryana, India

Harish Kumar
Food Technology, Amity University, Amity House, Jaipur, Rajasthan, India

Preeti Kundu
Maharshi Dayanand University (MDU), Rohtak, Haryana, India

Soma Maji
Centurion University of Technology and Management, Paralakhemundi, Odisha, India

Junaid Ahmad Malik
Department of Zoology, Government Degree College, Kashmir, Jammu and Kashmir, India

Ronit Mandal
Faculty of Land & Food Systems, University of British Columbia, Vancouver, BC, Canada

Sunil Meena
Department of Dairy Science and Food Technology, Banaras Hindu University (BHU), Varanasi, India

Rita Mehla
National Dairy Research Institute (NDRI), Karnal, India

Chander Mohan
Dairy Technology Division, National Dairy Research Institute (NDRI), Karnal, Haryana, India

Laxmana Naik
Dairy Chemistry and Bacteriology Section, ICAR-National Dairy Research Institute, SRS, Bengaluru, Karnataka, India

Pranali Nikam
Department of Chemistry, National Dairy Research Institute (NDRI), Karnal, Haryana, India

Heena Parmar
SMC College of Dairy Science, Kamdhenu University, Gujarat, India

Sandeep G. M. Prasad
Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Allahabad, Uttar Pradesh, India

Dinesh Chandra Rai
Department of Dairy Science and Food Technology, Banaras Hindu University (BHU), Varanasi, India

Rekha Rani
Department of Dairy Technology, West Bengal University of Animal and Fishery Sciences (WBUAFS), Mohanpur, West Bengal, India

Soniya Ranveer
Department of Chemistry, National Dairy Research Institute (NDRI), Karnal, Haryana, India

Suvartan G. Ranvir
Department of Dairy Chemistry, Warner College of Dairy Technology, Sam Higginbottom University of Agriculture, Technology & Sciences (SHUATS), Allahabad, Uttar Pradesh, India

Priyanka Singh Rao
Dairy Chemistry and Bacteriology Section, ICAR-National Dairy Research Institute, SRS, Bengaluru, Karnataka, India

Menon Rekha Ravindra
Dairy Engineering Department, SRS of ICAR-National Dairy Research Institute (NDRI), SRS, Bengaluru, Karnataka, India

Kuntal Roy
Department of Dairy Technology, West Bengal University of Animal and Fishery Sciences (WBUAFS), Mohanpur, West Bengal, India

Sunil Sakhala
Dairy Technology Division, National Dairy Research Institute, Karnal, Haryana, India

Bhagwan K. Sakhale
Department of Chemical Technology, Dr. Babasaheb Ambedkar Marathwada University, Jaisingpura, Aurangabad, Maharashtra, India

Khusbhu Sao
National Dairy Research Institute (NDRI), Karnal, Haryana, India

Sonu K. Shivanna
Dairy Chemistry Division, ICAR-National Dairy Research Institute, SRS, Adugodi, Bengaluru, Karnataka, India

Rahul R. Sindhani
Department of Chemical Technology, Dr. Babasaheb Ambedkar Marathwada University, Jaisingpura, Aurangabad, Maharashtra, India

Manju Singh
Department of Chemistry, KVA DVA College for Women, Railway Road, Karnal, Haryana, India

Divyang Solanki
Sumul Dairy, Surat, Gujarat, India

M. A. Syama
Dairy Development Department, Government of Kerala, Pattom, Thiruvananthapuram, Kerala, India

Srishty Tyagi
Dairy Chemistry Division, National Dairy Research Institute, Karnal, Haryana, India

ABBREVIATIONS & SYMBOLS

α-La	α-lactalbumin
α-Lg	α-lactalbumin
α_{s1}-CN	α_{s1}-casein
α_{s2}-CN	α_{s2}-casein
β	beta
β-CN	β-casein
β-Lg	β-lactoglobulin
κ	Kappa
κ–CN	κ-casein
2,4,6-TNBS	trinitrobenzene sulphonic acid
A	alpha
ACE	angiotensin converting enzyme
ADI	acceptable daily intake
AGMARK	agricultural marketing
AOAC	Association of Official Agricultural Chemists
API	atmospheric pressure ionization
Arg	arginine
As	arsenic
ASE	accelerated solvent extraction
ATR-FTIR	attenuated total reflection-Fourier transformer infrared spectroscopy
a_w	water activity
B	boron
BALB	Bagg Albino
BD	bulk density
BDDT	Braunner Demming Demming Teller
BI	browning index
BP	boiling point
BSA	bovine serum albumin
Ca	calcium
$CaCl_2$	calcium chloride
CAGR	compounded annual growth rate
CCP	calcium carbonate precipitation/colloidal calcium phosphate
CCPR	Codex Committee on Pesticide Residues

CD Value	conjugated dienes value
CI	Carr index/chemical ionization
Cl	chloride
CMC	critical moisture content/carboxy methyl cellulose
CN	casein
Co	cobalt
CODEX	Codex Alimentarius
cP	centipoise
CPPs	casein phosphopeptides
Cr	chromium
CTX	clinical trials exemption
Cu	copper
DAD	diode array detectors
DDT	dichlorodiphenyltrichloroethane
DEA	diethylaminopropyl
DF	diafiltration
DI	direct immersion
DNA	deoxyribonucleic acid
DSC	differential scanning calorimetry
ECD	electron capture detector
ED	electrodialysis
EDTA	ethylenediamine tetraacetic acid
EI	electron ionization
EM	evaporated milk
EMC	equilibrium moisture content
EPS	exopolysaccharides
ERH	equilibrium relative humidity
ESI	electrospray
F	fluorite
FAO	Food Agriculture Organization
Fe	iron
FF	flow function
FFA	free fatty acids
FITC	fluorescein isothiocyanate
FP	freezing point
FPD	flame photometric detector/freezing point depression
FSSAI	Food Safety and Standards Authority of India
FSSR	Food Safety and Standards Regulation
GAB	Guggenheime – Andersone – de Boer

GACR	compound annual growth rate
GC	gas chromatography
GCB	graphitized carbon black
GI	glycemic index
GLC	gas liquid chromatography
GMP	good manufacturing practices
GRAS	generally recognized as safe
H^+	hydronium ion
HC	heat capacity
HCH	hexachlorocyclohexane
HCT	heat coagulation time/temperature
HR	Hausner ratio
HRMS	high-resolution mass spectrometry
HS	headspace/heat stability
HTST	high temperature short time
I	iodine
IDF	International Dairy Federation
IFN-γ	interferon gamma
IgE	immunoglobulin E
IGF-1	insulin-like growth factor
Igs	immunoglobulins
IL-1	interleukin-1
IL-6	interleukin-6
IPP	isoleucine-proline-proline
IR	infrared
IT	ion trap
JMPR	Joint Meeting on Pesticide Residues
K	thermal conductivity
K	potassium
Kg/cm^2	kilogram per centimeter square
LAB	lactic acid bacteria
LC–MS	liquid chromatography–mass spectrometry
LLE	liquid–liquid extraction
LTI	low-temperature inactivation
LTLT	low-temperature long time
Lys	lysine
M	molar
MAE	microwave-assisted extraction
Max	maximum

MDA	malonaldehyde
MFGM	milk fat globule membrane
Mg	magnesium
MHR	modified Hausner ratio
Min	minimum
mL	milliliter
Mn	manganese
Mo	molybdenum
MPC	milk protein concentrate
MRLs	maximum residue limit
MS	mass spectrometry
MSI	moisture sorption isotherms
MSNF	milk solid not fat
MUFA	monounsaturated fatty acids
N	normal
Na	sodium
Na_2SO_4	sodium sulphate
NaCl	sodium chloride
NDDB	National Dairy Development Board
NEM	N-ethylmaleimide
NF	nano filtration
NFDM	non-fat dry milk
NH_2	aminopropyl
Ni	nickel
NLT	not less than
NMR	nuclear magnetic resonance
NMT	not more than
NPD	nitrogen and phosphorus detector
NSLB	nonstarter lactic acid bacteria
O/W	oil-in-water
OCPs	organochlorine pesticides
OCs	organochlorine
OPs	organophosphate pesticide
P	phosphorus
p-AnV	p-anisidine value
PA	plasminogen activator/poly-acrilate
PD	particle density
PDMS	polydimethylsiloxane
PG	propylene glycol

Pi	inorganic phosphates
Po	organic phosphates
POPs	persistent organic pollutants
PP	Proteose peptone
PP3	Proteose peptone 3
PSA	primary secondary amine
Psi	pounds per square inch
PTH	parathyroid hormone
PUFA	polyunsaturated fatty acids
PV	peroxide value/Polenke value
Q	quadrupole
QqQ	triple quadrupole
QTrap	hybrid quadrupole ion trap
QuEChERS	quick, easy, cheap, effective, rugged, and safe
RH	relative humidity
RI	refractive index
RM Value	Reichert-Meissl value
RNA	ribonucleic acid
RO	reverse osmosis
RP-HPLC	reverse phase high-performance liquid chromatography
RSSC	residual skin surface components
SCM	sweetened condensed milk
SDS-PAGE	sodium dodecyl sulphate–polyacrylamide gel electrophoresis
Se	selenium
SEM	scanning electron microscopy
SH	sulfhydryl
SHMP	sodium hexametaphosphate
Si	silicon
SMP	skim milk powder
SNF	solid not fat
SPE	solid phase extraction
SPME	solid-phase microextraction
SPT	sticky point temperature
SSHE	Scraped Surface Heat Exchangers
ST	surface tension
TBA Test	thiobarbituric acid test
TCA	trichloroacetic acid
TD	tapped density

T_g	glass transition temperature
Th1	Type 1 T helper
Th2	Type 2 T helper
TNF- α	tumor necrosis factor- α
TOF	time of flight
tPA:	tissue-type plasminogen activator
TRAP 5b	tartrate-resistant acid phosphatase 5b
TS	total solids
TV	Totox value
UAE	United Arab Emirates
UF	ultrafiltration
UFA	unsaturated fatty acids
UHPLC	ultra-high pressure liquid chromatography
UHT	ultra-high-temperature
uPA	urokinase plasminogen activator
US	United States of America
VPP	valine-proline-proline
W/O	water-in-oil
WHO	World Health Organization
WI	whiteness index
WMP	whole milk powder
WPC	whey protein concentrate
YI	yellowness index
Zn	zinc

PREFACE

Milk is a complete food that principally comprises water, milk fat, proteins, carbohydrate (lactose), and salts (minerals). Apart from these primary components, milk contains trace amounts of pigments, enzymes, vitamins, phospholipids, and gases. It is a highly nutritious medium, and the low acidity in milk provides a favorable environment for growth of pathogenic and spoilage causing organisms. For inactivating or killing these organisms and elongating the shelf life of milk products, it is necessary to substitute various types of thermal and nonthermal treatments. However, these treatments not only guarantee the safety of milk and milk products microbiologically, but simultaneously also cause changes in the nutritional quality, physicochemistry composition reactions, and formation of numerous types of components.

This book consists of four parts; **Part 1:** Milk and Milk Products: Constituents and Chemistry; **Part 2:** Physicochemical Properties of Milk and Milk Products; **Part 3:** Therapeutic Characteristics of Milk and Milk Products; **Part 4:** Processing and Characterization of Milk and Milk Products.

This book assumes a sound knowledge of raw milk composition, mineral constituents in milk, and manufacturing processes of butter and ice cream. It covers the physicochemical changes and compositional changes occurring during manufacturing and storage of milk, concentrated milk, butter, butter oil, and ice cream. This volume also encompasses the therapeutic characteristics of fermented milk and milk products, milk-derived bioactive peptides, and potential aspects of whey proteins in dairy products. Specialized methods like proteolysis in ultra high temperature (UHT), heat and acid coagulation of milk products, processing and characteristics of dry dairy milk powders, and methods to monitor pesticide residues in milk and milk products have also been elaborated on.

The book is intended for undergraduate and junior postgraduate students and be valuable for dairy science teaching staff, researchers, and industrial personnel interested in theoretical and practical knowledge of changes in physicochemical and compositional properties and heat-induced changes that occur during manufacturing and storage of dairy products, not just in improving the quality and performance of dairy products but also in a much wider context.

We hope that the book will answer some of the concerns raised by the readers regarding the chemistry of milk and milk products as well as pique their interest in learning more about these topics.

—*Editors*

PART I

CONSTITUENTS AND CHEMISTRY OF MILK AND MILK PRODUCTS

CHAPTER 1

CHEMISTRY OF RAW MILK: COMPOSITION, DISTRIBUTION, AND FACTORS

SUVARTAN G. RANVIR, ANKITA HOODA, AARTHY BOSE, and HARISH KUMAR

ABSTRACT

Generally, milk consists of 85–89% water, 2.5–6.0% fat, 2.9–5.0% protein, 3.6–5.5% lactose, and 0.6–0.9% minerals. The composition of raw milk depends on the species, breed, feed of animals, stage of lactation, number of parturitions, age of animal, health, the interval of milking, physical environment, and season. The major constituents of milk are interdependent with each other. Lactose chlorides and sodium ions contribute together for maintaining the osmotic pressure. Fat is an independent parameter, which changes with animal species, genetic, period of lactation, feed, an interval of feed, etc.

1.1 INTRODUCTION

All female mammalian species can secrete milk after giving birth to the newborn. The basic purpose of milk secretion is to supply the newborn neonate with immunity and nutrition.[42] The constituents of milk whether present in large or small quantities are responsible for these functions. The physiological immunological and nutritional necessities of all species vary significantly and hence the composition of milk secreted is different for each species.[15,51] The milk that is consumed by the human being consists of milk by cow, buffalo, sheep, and goat. Milk provides nearly all nutritional

The Chemistry of Milk and Milk Products: Physicochemical Properties, Therapeutic Characteristics, and Processing Methods. Megh R. Goyal, Suvartan Ranvir, & Junaid Ahmad Malik (Eds.)

components, which are needed for growth and development. Milk is a good source of milk fat, carbohydrate (lactose), protein, minerals, vitamin, and enzymes. However, milk is poor source of vitamin C and vitamin D.[36] Generally, milk is defined as a lacteal and biological secretion with a purpose to meet nutritional and immunological necessities of the newborn infant.[38,48]

The composition of milk not only varies among the species but also between the species depending on the individuality of animal, breed, health, age, lactation stage, climatic conditions, milking interval, etc.[41] A linear correlation among the protein concentration of milk and rate of growth of neonates has been reviewed by Benhart,[8] who reported that logarithm of days to double birth weight newborn is linearly related to the calories derived from protein. For example, it takes a human baby 120–180 days to double the birth weight and has 7% of calories coming from milk protein only; on the other hand, carnivores that take 7 days to double the body weight have >30% of energy coming from protein. Mother milk for human infants is the ideal food. Although cow, buffalo, and goat milk can be suitable replacement to feed newborns. Even the diet of human adults can be supplemented by milk of these species.[22,36]

This chapter focuses on milk constituents and various factors affecting the gross composition of milk.

1.2 GROSS COMPOSITION OF MILK

There are four broad categories of constituents[22] in the milk:

- Specific for organ and species: lipids and proteins.
- Specific for organ but not for species: milk carbohydrate.
- Specific for species but not for organ: some of the milk proteins.
- Neither species nor organ specific: vitamin, minerals, and water.

Milk comprises on an average of 87% water content, 3.9% fat content, 4.9% lactose content, 3.5% protein content, and 0.7% of minerals and miscellaneous components.[22,24,36] The gross composition of milk among species is presented in Table 1.1.

The advent of calving is concomitant and stimulus with biosynthesis and secretion of milk, a biological phenomenon triggered by lactogenic hormones. For the first few days after parturition, mammary glands secret, a fluid known as colostrum, which has a bitter taste, strong odor, faint reddish yellow color and contain a higher percentage of immunoglobulin. It is a rich source of all milk constituents except lactose, potassium, and pantothenic acid. Gradual changes from colostrum to normal milk are summarized in Table 1.2.[24,37]

TABLE 1.1 Gross Composition of Milk (%) of Different Species.

Species	Water	Protein	Fat	Ash	Lactose
Buffalo	82–84	3.3–3.6	7.0–11.5	0.8–0.9	4.5–5.0
Camel	86–88	3.0–3.9	2.9–5.4	0.6–0.9	3.3
Cow	85–87	3.2–3.8	3.7–4.4	0.7–0.8	4.8–4.9
Goat	87–88	2.9–3.7	4.0–4.5	0.8–0.9	3.6–4.2
Human	88–89	1.1–1.3	3.3–4.7	0.2–0.3	6.8–7.0
Sheep	79–82	5.6–6.7	6.9–8.6	0.9–0.1	4.3–4.8

Source: Jilo et al.[24]

TABLE 1.2 Transition from Colostrum to Normal Milk.

Time after calving (h)	Fat (%)	Total solids (%)	Total protein (%)	Albumin (%)	Casein (%)	Lactose (%)	Ash (%)
0	5.10	26.20	17.5	11.34	5.08	2.19	1.01
6	6.85	20.46	10.0	6.30	3.51	2.71	0.90
12	3.80	14.53	6.05	2.96	3.00	3.71	0.89
36	3.55	12.22	3.98	1.03	2.77	3.97	0.84
72	3.10	11.86	3.86	0.97	2.70	4.37	0.84
120	3.75	12.67	3.86	0.87	2.68	4.76	0.85

Source: Fundamental of Dairy Chemistry;[62] and Puppel et al.[50]

1.2.1 WATER

Water is called as silent nutrient.[19] Our body requires about 6–8 glasses of water daily for proper hydration of body. Water is the major constituent of milk in various species; and other various components are dissolved and emulsified into the water medium.[38] The solutes that are dissolved to a strength of 0.3 M contribute to depression in freezing point (by about 0.54°C).[18] Some amount of water is present in a bound form to protein and fat globule membranes and this water does not dissolve small ions and molecules. Milk contains about 87% of water and it is well source of water in diet. Water does not provide any energy as is done by fats, proteins, and carbohydrates; but it is most important for human metabolism. Water is also necessary for transporting many types of nutrients to organs and tissues.[22,36,62]

1.2.2 LIPIDS

The dietary fat provides energy for the newborn infant; and the amount of fat percentage secretion in milk by any species is dependent on the requirement of energy for survival of animals in cold environments.[41] Milk lipids are the source of essential fatty acids and fat-soluble vitamins (such as retinol, calciferol, tocopherol, and phytomenadione, and these are denoted by A, D, E, and K, respectively). Milk lipids principally contribute to improve the flavor and rheological characteristics of milk products.[30] Fatty acids are precursors of many types of flavoring compounds, such as, lactones and methyl ketones in some manufacturing processes.[4] On the other hand, lipids may also cause off-flavor because of hydrolysis or oxidation of lipid molecules (hydrolytic and oxidative rancidity).[4]

The milk fat consists of substances extractable by different methods, such as, simple extraction by a nonpolar solvent like chloroform, ether, and efficient method Rose–Gottlieb,[40] which uses solvents, i.e., ethanol, ammonium hydroxide, petroleum ether, and diethyl ether. The most common laboratory method to determine milk fat content is that of Gerber and Babcock,[26] in which sulfuric acid is used to release the fat. Milk fat mostly comprises of triglycerides (98%) and small amounts of mono and di-glycerides, fatty acids, phospholipids, sterols, and hydrocarbons.[3] The milk fat exists in the form of globules with diameter from 0.2 to 22 μm. This size distribution is affected by species, breed, age, stage of lactation, etc.[34]

1.2.3 CARBOHYDRATES

The major carbohydrate in milk is lactose and trace quantities of other carbohydrates (such as, glucose, fructose, galactosamine, glucosamine), and *N*-acetyl neuraminic acid.[6] The concentration of lactose varies with animal breed, individual animal, stage of lactation and udder disease, etc.[41] During lactation, the content of lactose significantly decreases.[17] In contrast during early lactation, protein and lipids decrease, while there is an increase during the second half of lactation. The content of lipids and proteins in milk can be inversely proportional to the amount of lactose content.[21,23]

Lactose and lipids are chief sources of energy in milk, where more energy is provided by lipids as compared with lactose content.[41] When animal is suffering from mastitis, the level of NaCl in milk is increased, which causes a depressed secretion of lactose.[47] The osmotic pressure in mammary system is maintained by lactose together with potassium (K), sodium (Na), and chloride (Cl) ions,[37] and any variation in lactose percentage. The milks of breeds and species that have higher lactose content would therefore have lower ash concentration and vice versa. The percentage of lactose and chloride in milk are also inversely related to milk secreted by udder-infected animals. The Koestler's chloride lactose test is used for identification of udder-infected milk[45] using following equation:

$$\text{Koestler Number} = 100 \times [(\text{Chloride }\%)/(\text{Lactose }\%)] \qquad (1)$$

Kosteler number of <2 and >3 indicates normal and abnormal milk, respectively.

1.2.4 PROTEINS

Bovine milk consists of 3.5% protein, which varies throughout the lactation. The milk proteins provide energy, essential amino acids, antimicrobial, and immune-boosting milk proteins (i.e., lactoferrin and immunoglobulin) to the newborn neonate.[11] The young ones have different requirements according to stage of maturity and hence this phenomenon is reflected in protein percentage of milk, which varies from 1 to 20%. The higher is the protein content, more is the rate of body growth.[57]

The milk protein consists of several classes of polypeptides. The major group is called caseins, which comprise of four kinds of polypeptides (namely: αs_1, αs_2, β, and K-casein), which further have their genetic variants, post-transitional modificants, and proteolysis products.[5] Casein exists in milk in the form of colloidal-calcium-phosphate, and in the form of micelles of 20–300 nm size. The next significant milk proteins are α-lactalbumin, β-lactoglobulin, blood serum albumin, and immunoglobulin and they are collectively known as whey protein.[61]

The classic method of milk protein determination is Kjeldahl analysis for Nitrogen determination.[54] The observed value is multiplied by 6.38 (as 15.67% of N is in milk protein) to get the value of total protein. The classical method of milk fractionation includes precipitation at pH of 4.6 to separate casein in precipitate, whereas whey protein in supernatant. All proteins can be precipitated by using an aliquot of 12% (w/v) trichloroacetic acid concentration.[13]

1.2.5 MINERALS

The amount of noncombustible matter in milk is designated as the ash content of milk. The normal value for ash content in milk is about 0.7%. The value of ash content is slightly increased in abnormal milk, such as, mastitis. Important minerals present in milk (Table 1.3) are calcium, magnesium, potassium, sodium, phosphorus, chloride, sulfur, and citrate.[13,16,22,36]

TABLE 1.3 Minerals Composition of Milk.

Constituent	Concentration	
	Range (mg/L)	**Mean value (mg/L)**
Calcium (Ca)	1000–1400	1000–1400
Carbonate	–	200
Chloride (Cl)	800-1400	1000
Citrate		1750
Inorganic phosphorus	–	750
Magnesium (Mg)	100–150	130
Phosphorus total	750–1100	950
Potassium (K)	1350–1550	1450
Sulfate (SO_4)	–	100

Source: Dairy Chemistry and Biochemistry;[13]
Guetouache et al.;[16] and Tamime et al.[59]

1.2.6 VITAMINS

Vitamins are classified as fat-soluble and water-soluble. Fat-soluble vitamins are retinol, calciferol, tocopherol, and phytomenadione, whereas water-soluble vitamins are B complex and ascorbic acid. Milk is a good source of vitamins except vitamin K (phytomenadione) and vitamin C. Vitamin E is the natural antioxidant, while vitamin B acts as coenzyme and is important in many enzymes catalyzed reaction. Vitamin A is required for development and growth, deficiency of vitamin A causes serious problem such as night blindness.[13,22,36,43] Comparative vitamin content in cow, buffalo, goat, and sheep milk is summarized in Table 1.4.

1.3 FACTORS AFFECTING COMPOSITION OF MILK

Composition of milk is not constant, and it varies depending on two major classes of factors: (1) animal factors (e.g., species, breed, different quarters of the udders, lactation period feed and nutritional level, disease, age of the animal, gestation, and hormones); and (2) environmental factors (e.g., milking interval, milking efficiency, season, exercise and excitement).

TABLE 1.4 Vitamin Content in Buffalo, Cow, Goat, and Sheep Milk (mg/100 g).

Vitamins	Buffalo milk	Cow milk	Sheep milk	Goat milk
Ascorbic Acid	2.5	0.09	4.16	1.29
Biotin	13	2.0	0.93	1.5
Calciferol	2.0	2.0	1.18	133
Cyanocobalamin	0.40	0.45	0.712	0.665
Niacin	0.17	0.09	0.416	0.27
Pantothenic acid	0.15	0.37	0.408	0.31
Pyridoxal	0.33	0.04	0.08	0.046
Retinol	69	46	146	185
Riboflavin	0.11	0.17	0.37	0.21
Thiamine	0.05	0.05	0.08	0.068
Tocopherol	0.19	0.21	-	0.03

Source: Khan et al.[30]

1.3.1 SPECIES

The changes in composition of milk in different species depend on so many other factors so that it is difficult to identify a specific factor liable for changes in gross composition of milk. Although every species milk composition is naturally planned to supply enough nutrition for natural rate of growth, which is an inherited trait of newborn mammals for the species.[22,36]

Rapid growth rate of animal is required more the concentrated milk components for this growth. Milk from all mammals is very different especially based on protein, fat, and lactose contents. Protein constituents principally contribute for doubling the birth weight of newborn mammals.[22,39] Protein content of rabbit milk contains very high amount of protein percentage, so that rapid newborn babies take very less time for doubling the birth weight. While human milk contains very low amount of protein because human baby doubling birth weight is very slow as compared with other mammals.[36] Apart from this, human milk looks as waterier (thinner) as compared with cow and buffalo milks because it contains less amount of fat and solid nonfat (SNF). While buffalo milk looks thicker as compared with human milk and cow milk because it contains higher amount of fat and SNF content.[22,36] Comparison of protein contents and time required for doubling body weight by newborn of mammals is given in Table 1.5.

TABLE 1.5 Development of the Newborn Babies in Relation to Protein (%) in Mother Milk.

Species	Protein % in milk	Time (days) required to double the birth weight
Cat	7	9.2
Cow	3.5	47
Human	1.6	180
Pig	5.21	14
Rabbit	10.38	6
Sheep	4.80	15

Source: Textbook of Dairy Chemistry[36]

1.3.2 BREED

The compositional variation in milk is strongly dependent on the type of breed. The change in fat is more pronounced among different breeds of animals, while other constituents are also slightly changed. It has been reported that as the fat percentage is increased then SNF content is also increased and vice versa.[10,12,41] Many comparative research studies on variation in gross composition milk have been carried out for different breeds. The available data is very wide because it is very difficult to get all the information that could lead to correct appreciation of the precise extent of impact by breeds. The data on the composition of milk for different breed milks are summarized in Tables 1.6–1.8.

TABLE 1.6 Differences in Milk Composition (%) among Different Breeds.

Component of milk	Animal breed					
	Jersey	Friesian	Short Horn	Ayrshire	Guernsey	Red Poll
Fat	5.14	3.45	3.03	3.85	4.96	4.24
Lactose	5.04	4.65	4.89	5.02	4.98	4.77
Mineral	0.75	0.68	0.73	0.69	0.75	0.72
Protein	3.80	3.15	3.32	3.34	3.84	3.70
Solid nonfat	9.59	8,48	8.94	9.05	9.57	13.28
Water	85.27	88.01	87.43	87.10	85.47	86.72

Source: Textbook of Dairy Chemistry;[36] Dairy Chemistry and Animal Nutrition[52]; Alphonsus et al.[2]