

VITAMINS IN
ANIMAL NUTRITION

无
号
区

S82-51@
W 02

S 816

C 972

051510

VITAMINS IN ANIMAL NUTRITION

Comparative Aspects to
Human Nutrition

Lee Russell McDowell

Animal Science Department
University of Florida
Gainesville, Florida



ACADEMIC PRESS, INC.

Harcourt Brace Jovanovich, Publishers

San Diego New York Berkeley Boston

London Sydney Tokyo Toronto

COPYRIGHT © 1989 BY ACADEMIC PRESS, INC.

ALL RIGHTS RESERVED.

NO PART OF THIS PUBLICATION MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM OR BY ANY MEANS, ELECTRONIC OR MECHANICAL, INCLUDING PHOTOCOPY, RECORDING, OR ANY INFORMATION STORAGE AND RETRIEVAL SYSTEM, WITHOUT PERMISSION IN WRITING FROM THE PUBLISHER.

ACADEMIC PRESS, INC.

1250 Sixth Avenue

San Diego, California 92101

United Kingdom Edition published by

ACADEMIC PRESS LIMITED

24-28 Oval Road, London NW1 7DX

Library of Congress Cataloging-in-Publication Data

McDowell, L.R., Date

Vitamins in animal nutrition.

(Animal feeding and nutrition)

Includes index.

1. Vitamins in animal nutrition. 2. Vitamins in human nutrition. I. Title. II. Series.

SF98.V5M32 1989 636.08'52 88-16722

ISBN 0-12-483372-1 (alk. paper)

PRINTED IN THE UNITED STATES OF AMERICA

89 90 91 92 9 8 7 6 5 4 3 2 1

351510

VITAMINS IN
ANIMAL NUTRITION

ANIMAL FEEDING AND NUTRITION

A Series of Monographs and Treatises

Tony J. Cunha, Editor

Distinguished Service Professor Emeritus
University of Florida
Gainesville, Florida

and

Dean Emeritus, School of Agriculture
California State Polytechnic University
Pomona, California

Tony J. Cunha, SWINE FEEDING AND NUTRITION, 1977

W. J. Miller, DAIRY CATTLE FEEDING AND NUTRITION, 1979

Tilden Wayne Perry, BEEF CATTLE FEEDING AND NUTRITION, 1980

Tony J. Cunha, HORSE FEEDING AND NUTRITION, 1980

Charles T. Robbins, WILDLIFE FEEDING AND NUTRITION, 1983

Tilden Wayne Perry, ANIMAL LIFE-CYCLE FEEDING AND NUTRITION, 1984

Lee Russell McDowell, NUTRITION OF GRAZING RUMINANTS IN WARM
CLIMATES, 1985

Ray L. Shirley, NITROGEN AND ENERGY NUTRITION OF RUMINANTS, 1986

Peter R. Cheeke, RABBIT FEEDING AND NUTRITION, 1987

Lee Russell McDowell, VITAMINS IN ANIMAL NUTRITION, 1989

D. J. Minson, FORAGE AND RUMINANT NUTRITION, 1989

This book is dedicated with appreciation
to my parents,
to my wife, Lorraine,
and to my daughters,
Suzannah, Jody, and Teresa

Foreword

This is the tenth in a series of books about animal feeding and nutrition. The books in this series are designed to keep the reader abreast of the rapid developments that have occurred in this field in recent years. As the volume of scientific literature expands, interpretation becomes more complex, and a continuing need exists for summation and for up-to-date books.

This book on vitamins is written by Dr. Lee R. McDowell, a distinguished scientist in animal nutrition, who was also editor of *Nutrition of Grazing Ruminants in Warm Climates* (Academic Press, 1985). For the past 23 years, he has been working on animal nutrition studies at the University of Florida and with numerous collaborating animal scientists in Latin America, Africa, Asia, and other areas. He has lectured throughout the world and has collected research data, photographs, and other materials of value for this book. His expertise and knowledge have been greatly enriched by contact with many of the world's leading nutrition scientists.

For many years, there has been a great need for a single book on vitamins covering both animals and humans. Dr. McDowell has done a magnificent job of reviewing the vitamin literature and condensing it into one textbook. He covers the basic chemical, metabolic, and functional role of vitamins. Moreover, he devotes proper consideration to vitamin supplementation. The book is well illustrated with a wealth of valuable photographs depicting vitamin deficiencies in livestock, laboratory animals, and humans.

In addition to worldwide use as a textbook, this book should also be of considerable value to research and extension specialists, teachers, students, feed manufacturers, farmers, and others dealing with the livestock industry. Animal industry personnel, veterinarians, and those interested in comparative nutrition will find this book very useful. It should be valuable for anyone concerned with vitamin nutrition.

New feed and food crops, improved methods of production and processing, increased productivity of animals and crops, changes in animal products including more lean and less fat in meat and less fat in milk, longer shelf life requirements

of food products, and a myriad of new technological developments have resulted in a need to reevaluate vitamin supplementation. This book is timely and valuable in bringing the vitamin field up-to-date and in discussing supplementation needs.

Tony J. Cunha

Preface

Vitamins in Animal Nutrition contains 18 chapters of concise, up-to-date information on vitamin nutrition for both animals and humans. The first chapter deals with the definition of vitamins, general considerations, and the fascinating history of these nutrients. Chapters 2 through 15 discuss the 14 established vitamins in relation to history; chemical structure, properties, and antagonists; analytical procedures; metabolism; functions; requirements; sources; deficiency; supplementation; and toxicity. Chapter 16 deals with other vitamin-like substances, and Chapter 17 reviews the importance of essential fatty acids. The final chapter discusses vitamin supplementation considerations.

It is hoped that this book will be of worldwide use as a textbook and as an authoritative reference book for use by research and extension specialists, feed manufacturers, teachers, students, and others. An attempt has been made to provide a balance between animal nutrition and clinical human nutrition. Likewise, a comparison between the balance of chemical, metabolic, and functional aspects of vitamins and their practical and applied considerations has been made.

A unique feature is the description of the practical implications of vitamin deficiencies and excesses and the conditions that might occur with various animal species and humans. A large number of photographs illustrate vitamin deficiencies in farm livestock, laboratory animals, and humans. Unlike other textbooks, this one places strong emphasis on vitamin supplementation in each chapter and devotes the last chapter to this subject.

In preparing this book, I have obtained numerous suggestions from eminent scientists both in the United States and in other countries of the world. I wish to express my sincere appreciation to them and to those who supplied photographs and other material used. I am especially grateful to the following: C. B. Ammerman, L. B. Bailey, R. B. Becker, D. K. Beede, B. J. Bock, H. L. Chapman, J. H. Conrad, G. L. Ellis, R. H. Harms, J. F. Hentges, J. K. Loosli, R. M. Mason, R. Miles, R. L. Shirley, R. R. Streiff, and W. B. Weaver (Florida); R. T. Lovell and H. E. Sauberlich (Alabama); O. Balbuena, B. J. Carrillo, and B. Ruksan (Argentina); H. Heitman (California); J. M. Bell, M. Hidiroglou, and N. Hidiroglou (Canada); N. Ruiz (Colombia); N. Comben (England); M. Sand-

holm (Finland); L. S. Jensen (Georgia); T. B. Keith (deceased) (Idaho); A. H. Jensen (Illinois); V. Ramadas Murthy (India); A. Prabowo (Indonesia); V. Catron (deceased), and V. C. Speer (Iowa); G. L. Cromwell (Kentucky); G. F. Combs (Maryland); F. J. Stare (Massachusetts); R. W. Luecke, E. R. Miller, R. C. Piper, J. W. Thomas, and D. E. Ullrey (Michigan); R. T. Holman and T. W. Sullivan (Minnesota); V. Herbert, L. E. Kook, M. C. Latham, and M. L. Scott (New York); A. Helgebostad and H. Rimeslatten (Norway); D. E. Becker (Ohio); P. R. Cheeke, D. C. Church, O. H. Muth, and J. E. Oldfield (Oregon); D. S. McLaren (Scotland); J. R. Couch and T. M. Ferguson (deceased) (Texas); D. C. Dobson (Utah); J. P. Fontenot, M. D. Lindemann, and L. M. Potter (Virginia); J. R. Carlson, J. A. Froseth, and L. L. Madsen (deceased) (Washington); and M. L. Sunde (Wisconsin). Appreciation is expressed to company representatives, including G. Patterson (Chas. Pfizer Co); J. C. Bauernfeind, T. M. Fry, E. L. MacDonald, L. A. Peterson, and S. N. Williams (Hoffmann-LaRoche, Inc.); C. H. McGinnis (Rhône-Poulenc, Inc.); and A. T. Forrester (The Upjohn Co.). Special thanks go to J. P. Fontenot for the preliminary planning of this book, and to P. R. Cheeke and J. E. Oldfield for editing and providing useful suggestions for the entire publication.

I am particularly grateful to Nancy Wilkinson and Lorraine M. McDowell for their useful suggestions and assistance in the editing of the entire book. Likewise, I wish to acknowledge with thanks and appreciation the skill and care of Patricia French for overseeing the typing and proofreading of chapters, and also thank Vanessa Carbia for her valuable assistance. Also, I am indebted to the Animal Science Department of the University of Florida for providing the opportunity and support for this undertaking. Finally, I thank Tony J. Cunha for encouraging me to undertake the responsibility of writing this book, and for the experience of his expertise on this subject.

Lee Russell McDowell

Contents

Foreword	xiii
Preface	xv
1 Introduction and Historical Considerations	1
I. Definition of Vitamins	1
II. Classification of Vitamins	1
III. Vitamin Nomenclature	3
IV. Vitamin Requirements	3
V. Vitamin Occurrence	4
VI. History of the Vitamins	5
2 Vitamin A	10
I. Introduction	10
II. History	10
III. Chemical Structure and Properties	12
IV. Analytical Procedures	15
V. Metabolism	15
VI. Functions	20
VII. Requirements	27
VIII. Natural Sources	30
IX. Deficiency	35
X. Supplementation	48
XI. β -Carotene Function Independent of Vitamin A	51
XII. Toxicity	52
3 Vitamin D	55
I. Introduction	55
II. History	55
III. Chemical Structure, Properties, and Antagonists	57
IV. Analytical Procedures	59
V. Metabolism	60

VI. Functions	65
VII. Requirements	69
VIII. Natural Sources	73
IX. Deficiency	75
X. Supplementation	84
XI. Toxicity	87
4 Vitamin E	93
I. Introduction	93
II. History	93
III. Chemical Structure and Properties	94
IV. Analytical Procedures	96
V. Metabolism	97
VI. Functions	98
VII. Requirements	101
VIII. Natural Sources	104
IX. Deficiency	107
X. Supplementation	128
XI. Toxicity	131
5 Vitamin K	132
I. Introduction	132
II. History	132
III. Chemical Structure, Properties, and Antagonists	133
IV. Analytical Procedures	136
V. Metabolism	136
VI. Functions	138
VII. Requirements	140
VIII. Natural Sources	142
IX. Deficiency	144
X. Supplementation	151
XI. Toxicity	153
6 Thiamin	155
I. Introduction	155
II. History	155
III. Chemical Structure, Properties, and Antagonists	156
IV. Analytical Procedures	157
V. Metabolism	158
VI. Functions	159
VII. Requirements	161
VIII. Natural Sources	163
IX. Deficiency	165
X. Supplementation	179
XI. Toxicity	181

7 Riboflavin	183
I. Introduction	183
II. History	183
III. Chemical Structure, Properties, and Antagonists	184
IV. Analytical Procedures	186
V. Metabolism	186
VI. Functions	187
VII. Requirements	190
VIII. Natural Sources	192
IX. Deficiency	194
X. Supplementation	207
XI. Toxicity	209
8 Niacin	210
I. Introduction	210
II. History	210
III. Chemical Structure, Properties, and Antagonists	212
IV. Analytical Procedures	213
V. Metabolism	213
VI. Functions	216
VII. Requirements	217
VIII. Natural Sources	219
IX. Deficiency	221
X. Supplementation	233
XI. Toxicity	235
9 Vitamin B₆	236
I. Introduction	236
II. History	236
III. Chemical Structure, Properties, and Antagonists	237
IV. Analytical Procedures	238
V. Metabolism	239
VI. Functions	240
VII. Requirements	242
VIII. Natural Sources	245
IX. Deficiency	246
X. Supplementation	253
XI. Toxicity	255
10 Pantothenic Acid	256
I. Introduction	256
II. History	256
III. Chemical Structure, Properties, and Antagonists	257
IV. Analytical Procedures	258

V. Metabolism	259
VI. Functions	259
VII. Requirements	261
VIII. Natural Sources	264
IX. Deficiency	265
X. Supplementation	273
XI. Toxicity	274
11 Biotin	275
I. Introduction	275
II. History	275
III. Chemical Structure, Properties, and Antagonists	276
IV. Analytical Procedures	277
V. Metabolism	278
VI. Functions	278
VII. Requirements	279
VIII. Natural Sources	281
IX. Deficiency	282
X. Supplementation	294
XI. Toxicity	297
12 Folicin	298
I. Introduction	298
II. History	298
III. Chemical Structure, Properties, and Antagonists	299
IV. Analytical Procedures	301
V. Metabolism	302
VI. Functions	304
VII. Requirements	306
VIII. Natural Sources	308
IX. Deficiency	310
X. Supplementation	321
XI. Toxicity	322
13 Vitamin B₁₂	323
I. Introduction	323
II. History	323
III. Chemical Structure, Properties, and Antagonists	325
IV. Analytical Procedures	326
V. Metabolism	327
VI. Functions	329
VII. Requirements	332
VIII. Natural Sources	334
IX. Deficiency	335
X. Supplementation	344
XI. Toxicity	346

14 Choline	347
I. Introduction	347
II. History	347
III. Chemical Structure and Properties	348
IV. Analytical Procedures	349
V. Metabolism	349
VI. Functions	350
VII. Requirements	352
VIII. Natural Sources	354
IX. Deficiency	355
X. Supplementation	362
XI. Toxicity	364
15 Vitamin C	365
I. Introduction	365
II. History	365
III. Chemical Structure, Properties, and Antagonists	367
IV. Analytical Procedures	368
V. Metabolism	369
VI. Functions	370
VII. Requirements	372
VIII. Natural Sources	374
IX. Deficiency	376
X. Supplementation	383
XI. Toxicity	387
16 Vitamin-like Substances	388
I. Introduction	388
II. <i>myo</i> -Inositol (Inositol)	388
III. Carnitine	393
IV. <i>p</i> -Aminobenzoic Acid (PABA)	395
V. Polyphenols (Flavonoids)	396
VI. Lipoic Acid (Thioctic Acid)	396
VII. Coenzyme Q	396
VIII. "Vitamin B ₁₃ " (Orotic Acid)	397
IX. "Vitamin B ₁₅ " (Pangamic Acid)	397
X. "Vitamin B ₁₇ " (Laetrial)	397
XI. "Vitamin H ₁ " (Gerovital)	397
XII. "Vitamin U" (Cabagin)	398
XIII. Glucose Tolerance Factor	398
XIV. Other Vitamin-like Substances	398
17 Essential Fatty Acids	400
I. Introduction	400
II. History	400

III. Chemical Structure and Properties	401
IV. Analytical Procedures	402
V. Metabolism and Functions	402
VI. Requirements	408
VII. Natural Sources	412
VII. Deficiency	412
IX. Supplementation	419
X. Toxicity	420
18 Vitamin Supplementation	422
I. Introduction	422
II. Factors Resulting in Inadequate Dietary Intakes of Vitamins	422
III. Factors Affecting Vitamin Requirements and Vitamin Utilization	427
IV. Optimum Vitamin Allowances	430
V. Vitamin Supplementation Most Needed by Livestock	432
VI. Vitamin Supplementation for Humans	436
VII. Providing Vitamin Supplements	439
VIII. Formulating Vitamin Premixes	443
Bibliography	445
Appendix	468
Index	479

Introduction and Historical Considerations

I. DEFINITION OF VITAMINS

Vitamins are defined as a group of complex organic compounds present in minute amounts in natural foodstuffs that are essential to normal metabolism and lack of which in the diet causes deficiency diseases. Vitamins consist of a mixed group of chemical compounds and are not related to each other as are proteins, carbohydrates, and fats. Their classification together depends not on chemical characteristics but on function. Vitamins are differentiated from the trace elements, also present in the diet in small quantities, by their organic nature.

Vitamins are required in trace amounts (micrograms to milligrams per day) in the diet for health, growth, and reproduction. Omission of a single vitamin from the diet of a species that requires it will produce deficiency signs and symptoms. Many of the vitamins function as coenzymes (metabolic catalysts); others have no such role, but perform certain essential functions.

Some vitamins deviate from the preceding definition in that they do not always need to be constituents of food. Certain substances that are considered to be vitamins are synthesized by intestinal tract bacteria in quantities that are often adequate for body needs. However, a clear distinction is made between vitamins and substances that are synthesized in tissues of the body. Ascorbic acid, for example, can be synthesized by most species of animals, except when they are young or under stress conditions. Likewise, niacin can be synthesized from the amino acid tryptophan and vitamin D from action of ultraviolet light on precursor compounds in the skin. Thus, under certain conditions and for specific species, vitamin C, niacin, and vitamin D would not always fit the classic definition of a vitamin.

II. CLASSIFICATION OF VITAMINS

Classically, vitamins have been divided into two groups based on their solubilities in fat solvents or in water. Thus, fat-soluble vitamins include A, D, E, and K, while vitamins of the B complex, C, and others are classified as water soluble. Fat-soluble vitamins are found in feedstuffs in association with lipids.