



CHING KUANG CHOW

FATTY ACIDS IN FOODS *and their* HEALTH IMPLICATIONS

THIRD EDITION

edited by

CHING KUANG CHOW



CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the
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CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

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No claim to original U.S. Government works
Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number-10: 0-8493-7261-5 (Hardcover)
International Standard Book Number-13: 978-0-8493-7261-2 (Hardcover)

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Library of Congress Cataloging-in-Publication Data

Fatty acids in foods and their health implications / editor, Ching K. Chow. -- 3rd ed.
p. ; cm. -- (Food science and technology ; 170)

"A CRC title."

Includes bibliographical references and index.

ISBN 978-0-8493-7261-2 (hardcover : alk. paper)

1. Fatty acids in human nutrition. 2. Food--Fat content. 3. Fatty acids--Health aspects. I. Chow, Ching Kuang, 1940- II. Series: Food science and technology (Taylor & Francis) ; 170.

[DNLM: 1. Fatty Acids. 2. Dietary Fats. 3. Nutrition Physiology. W1 FO509P v.170 2007 / QU 90 F254 2007]

QP752.F35F38 2007
612.3'97--dc22

2007007718

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THIRD EDITION

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Preface

The first edition of this book volume was published in 1992, and the second edition in 1999 by Marcel Dekker, Inc., New York. Since then, volumes of new information on the fatty acids in various foods and food products, as well as their biological health effects have become available. In addition to quantity, the type of fatty acids consumed plays an important role in the etiology of a variety of degenerative diseases, including cardiovascular disease, cancer, immunity and inflammatory disease, renal disease, diabetes, neuromuscular disorders, liver disease, visual dysfunction, psychiatric disorders, and aging. Understanding the mechanisms by which fatty acids exert their biological effects is important in unraveling the pathogenesis of these disorders, and may help providing effective preventive measures.

Both animal- and plant-derived food products contain fat. Food fat provides taste, consistency, and helps us feel full. Fat is a major source of energy for the body, and aids in the absorption of lipid soluble substances including vitamins A, D, E, and K. Dietary fat is essential for normal growth, development, and maintenance, and serves a number of important functions. Increasing evidence indicates that fatty acids and their derived substances may mediate critical cellular events, including activation and expression of genes, and regulation of cellular signaling.

New reports or findings dealing with the health effects of various fatty acids have always commanded a strong public interest. In recent years, omega-3 and *trans* fatty acids have received more attention than others. On September 8, 2004, the Food and Drug Administration announced the availability of a qualified health claim for reduced risk of coronary heart disease on conventional foods that contain omega-3 fatty acids, eicosapentaenoic acid, and docosahexaenoic acid. While these fatty acids are not essential to the diet, scientific evidence indicates that these fatty acids may be beneficial in reducing coronary heart disease. On the other hand, recent scientific reports, expert panels, and studies concluded that consumption of *trans* fatty acids contributes to increased low-density lipoprotein cholesterol levels, which increase the risk of coronary heart disease. The Food and Drug Administration's final rule on *trans* fatty acids (or *trans* fat) requires manufacturers to list the amount of *trans* fat per serving on a separate line under saturated fat on the Nutrition Facts panel. As of January 1, 2006, food manufacturers must list the content of *trans* fat on the nutrition label. The health effects of α -linolenic acids and conjugated linoleic acid have also received considerable recent attention.

In recent decades, the prevalence of obesity or overweight has increased steadily in the United States and elsewhere. Currently over 40% of the adult population in the United States are considered as overweight or obese. Obesity is an important risk factor contributing to the development of the three leading causes of death—cardiovascular disease, cancer, and diabetes—and other disorders in the United States. As fat has much higher energy density than that of protein and carbohydrate, dietary fat is often blamed as the source of excess energy, although it is difficult to differentiate the effects of dietary fat and other energy nutrients independent of total energy intake. Evaluating trends in energy nutrient intake is useful in understanding the role of individual energy nutrients in the development of obesity and obesity-related illness over time. Also, investigation of the role of fatty acids in satiating effect and energy homeostasis is important in understanding food intake and energy balance issues.

Partly owing to the high-energy density, concerns over health problems associated with obesity and overweight have led to the development of several fat substitutes. The rapid advance in molecular biology and biotechnology has allowed for selective alteration of fatty acid composition in oil crops. It is now possible to commercially produce oil crops that contain a desirable proportion of specific fatty acids. Owing to distinct biological and health effects of various fatty acids, manipulation of the lipid composition in oil crops is likely to impact our well-being and economy enormously.

In addition to updating original chapters on the basis of available recent information, the following new chapters are added to cover the subject areas that were not covered or not adequately

covered in the second edition: Fatty Acids in Fermented Food Products (Chapter 13), Effect of Heating and Frying on Oil and Food Fatty Acids (Chapter 20), Consumption of Fatty Acids (Chapter 21), Significance of Dietary γ -Linolenate in Biological Systems: Alternation of Inflammation and Proliferative Process (Chapter 32), Biological Effects of α -Linolenic Acid (Chapter 33), Biological Effects of Conjugated Linoleic Acid (Chapter 34), The Role of Omega-3 Polyunsaturated Fatty Acids in Food Intake and Energy Homeostasis (Chapter 35), and Fatty Acid and Cognition, Behavior and Brain Development, and Mood Disease (Chapter 39). Also, the following chapters were completely rewritten: Fatty Acids in Meat and Meat Products (Chapter 5), Fatty Acids in Milk Fat (Chapter 6), The Effects of Dietary Fatty Acids in Fatty Acid Metabolism (Chapter 23), Dietary Fatty Acids and Eicosanoids (Chapter 28), Fatty Acids and Aging (Chapter 40), and Essential Fatty Acids and Visual Dysfunction (Chapter 43). At the same time, several chapters that appeared in the second edition were not included in the third edition.

This updated and expanded book volume presents the current status of fatty acids in common foods and food products. It also aims to provide readers with state-of-the-art information on the widely diversified health implications of fatty acids. However, as the precise role of fatty acids in the etiology of various degenerative disorders is yet to be delineated, it is not the intention of this book volume to present a unified view on the health implications of fatty acids or to provide guidelines for fatty acid consumption.

I would like to express my sincere appreciation to all the authors of this book volume for their cooperation and excellent contributions. Without their participation and efforts this project would not be a reality. Also, I would like to thank Susan Lee and Amber Donley of Taylor & Francis for their assistance and support during the course of the project. Finally I wish to thank my wife Shukwei for her understanding and patience over the past many years.

Ching Kuang Chow

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Contents

Preface	ix
Contributors	xi
Chapter 1 Fatty Acid Classification and Nomenclature	1
<i>Kelly Lobb and Ching Kuang Chow</i>	
Chapter 2 Chemical and Physical Properties of Fatty Acids	17
<i>John M. deMan</i>	
Chapter 3 Application of Gas-Liquid Chromatography to Lipid Separation and Analysis: Qualitative and Quantitative Analysis	47
<i>Robert G. Ackman</i>	
Chapter 4 Isotopic Methods for Assessing Lipid Metabolism	67
<i>Joanne K. Kelleher, Carolina B. Cabral, and Jennifer M.K. Cheong</i>	
Chapter 5 Fatty Acids in Meat and Meat Products	87
<i>J. D. Wood, M. Enser, R. I. Richardson, and F. M. Whittington</i>	
Chapter 6 Fatty Acids in Milk Fat	109
<i>Donald L. Palmquist and Robert G. Jensen</i>	
Chapter 7 Fatty Acids in Poultry and Egg Products	127
<i>Austin H. Cantor, Eric A. Decker, and Victoria P. Collins</i>	
Chapter 8 Fatty Acids in Fish and Shellfish	155
<i>Robert G. Ackman</i>	
Chapter 9 Fatty Acids in Vegetables and Vegetable Products	187
<i>Geza Bruckner and Andrew C. Peng</i>	
Chapter 10 Fatty Acids in Oilseeds (Vegetable Oils)	227
<i>Pamela J. White</i>	
Chapter 11 Fatty Acids in Fruits and Fruit Products	263
<i>Basil S. Kamel and Yukio Kakuda</i>	
Chapter 12 Fatty Acids in Food Cereal Grains and Grain Products	303
<i>Robert Becker</i>	
Chapter 13 Fatty Acids in Fermented Food Products	317
<i>Sue Joan Chang and Ching Kuang Chow</i>	
Chapter 14 Fatty Acid Content of Convenience Foods	335
<i>Maria G. Boosalis</i>	
Chapter 15 Trans-Fatty Acids in Foods	377
<i>Margaret C. Craig-Schmidt and Carmen A. Teodorescu</i>	
Chapter 16 Genetic Alteration of Food Fats and Oils	439
<i>Earl G. Hammond</i>	

Chapter 17 Fat-Based Fat Substitutes	461
<i>Casimir C. Akoh</i>	
Chapter 18 Commercial Applications of Fats in Foods	473
<i>Ronald Jandacek</i>	
Chapter 19 Effects of Processing and Storage on Fatty Acids in Edible Oils	493
<i>Vickie Tatum and Ching Kuang Chow</i>	
Chapter 20 Effect of Heating and Frying on Oil and Food Fatty Acids	511
<i>Francisco J. Sánchez-Muniz, Sara Bastida, Gloria Márquez-Ruiz, and Carmen Dobarganes</i>	
Chapter 21 Consumption of Fatty Acids	545
<i>Sue Joan Chang and Ching Kuang Chow</i>	
Chapter 22 Absorption and Transport of Dietary Lipid	561
<i>Vernon A. Welch and Jürgen T. Borlak</i>	
Chapter 23 The Effects of Dietary Fatty Acids on Lipid Metabolism	591
<i>Madhuri Vemuri and Darshan S. Kelley</i>	
Chapter 24 Dietary Fatty Acids and Minerals	631
<i>Elizabeth A. Droke and Henry C. Lukaski</i>	
Chapter 25 Interaction of Dietary Fatty Acids, Carbohydrates, and Lipids on Carbohydrate Metabolism	651
<i>Béla Szepesi</i>	
Chapter 26 Reappraisal of the Essential Fatty Acids	675
<i>Robert S. Chapkin</i>	
Chapter 27 Fatty Acids and Membrane Function	693
<i>Carolyn D. Berdanier</i>	
Chapter 28 Dietary Fatty Acids and Eicosanoids	713
<i>Joo Y. Lee and Daniel H. Hwang</i>	
Chapter 29 Polyunsaturated Fatty Acids and Regulation of Gene Expression	727
<i>Harini Sampath and James M. Ntambi</i>	
Chapter 30 Fatty Acids, Lipids, and Cellular Signaling	741
<i>Geza Bruckner</i>	
Chapter 31 Safety and Health Effects of <i>Trans</i> Fatty Acids	757
<i>J. Edward Hunter</i>	
Chapter 32 Significance of Dietary γ -Linolenate in Biological Systems: Attenuation of Inflammatory and Proliferative Processes	791
<i>Vincent A. Ziboh</i>	
Chapter 33 Biological Effects of Alpha-Linolenic Acid	813
<i>Luc Djoussé</i>	
Chapter 34 Biological Effects of Conjugated Linoleic Acid	825
<i>Yung-Sheng Huang, Teruyoshi Yanagita, Koji Nagao, and Kazunori Koba</i>	

Chapter 35	The Role of Omega-3 Polyunsaturated Fatty Acids in Food Intake and Energy Homeostasis	837
<i>Richard S. Weisinger, Denovan P. Begg, Lauren Stahl, Harrison S. Weisinger, Andrew J. Sinclair, and Markandeya Jois</i>		
Chapter 36	Biological Effects of Oxidized Fatty Acids	855
<i>Ching Kuang Chow</i>		
Chapter 37	Satiating Effects of Fat	879
<i>Zoe S. Warwick, Colleen M. McGuire, and Christina Revelle</i>		
Chapter 38	Fatty Acids and Growth and Development	899
<i>Margit Hamosh</i>		
Chapter 39	Fatty Acids, and Cognition, Behavior, Brain Development, and Mood Diseases	935
<i>Jean-Marie Edouard Bourre</i>		
Chapter 40	Fatty Acids and Aging	955
<i>José L. Quiles and M. Carmen Ramírez-Tortosa</i>		
Chapter 41	Dietary Fat, Immunity, and Inflammatory Disease	977
<i>Gilbert A. Boissonneault</i>		
Chapter 42	Fatty Acids and Liver Disease	1007
<i>Amin A. Nanji and Bassam A. Nassar</i>		
Chapter 43	Essential Fatty Acids and Visual Dysfunction	1019
<i>Algis J. Vingrys and Anne E. Weymouth</i>		
Chapter 44	Fatty Acids and Cardiovascular Disease	1061
<i>Geza Bruckner</i>		
Chapter 45	Dietary Fatty Acids and Cancer	1085
<i>Howard Perry Glauert</i>		
Chapter 46	Fatty Acids and Renal Disease	1109
<i>Stuart K. Ware</i>		
Chapter 47	Fatty Acid Metabolism in Diabetes	1145
<i>Sam J. Bhatena</i>		
Chapter 48	Fatty Acid Metabolism in Skeletal Muscle and Nerve, and in Neuromuscular Disorders	1197
<i>Charles J. Rebouche and Jeffrey K. Yao</i>		
Chapter 49	Fatty Acids and Psychiatric Disorders	1229
<i>Sarah M. Conklin, Ravinder D. Reddy, Matthew F. Muldoon, and Jeffrey K. Yao</i>		
Index	1257

1 Fatty Acid Classification and Nomenclature

Kelly Lobb and Ching Kuang Chow

CONTENTS

I. Introduction	1
II. Nomenclature	1
III. Saturated Fatty Acids	3
IV. Unsaturated Fatty Acids	6
V. Oxygenated Fatty Acids	11
VI. Cyclic Fatty Acids	14
VII. Conclusion	14
References	14

I. INTRODUCTION

Fats or lipids consist of numerous chemical compounds, including monoglycerides, diglycerides, triglycerides, phosphatides, cerebrosides, sterols, terpenes, fatty alcohols, and fatty acids. Fatty acids constitute the main component of phospholipids, triglycerides, diglycerides, monoglycerides, and sterol esters. Fatty acids consist of elements, such as carbon, hydrogen, and oxygen, that are arranged as a linear carbon chain skeleton of variable length with a carboxyl group at one end. Fatty acids can be saturated (no double bond), monounsaturated (one double bond), or polyunsaturated (two or more double bonds), and are essential for energetic, metabolic, and structural activities.

Food scientists, nutritionists, biochemists, chemists, and biomedical scientists alike recognize the need for a coherent nomenclature for fatty acids. There are a number of nomenclature systems for fatty acids, and some researchers continue to name fatty acids traditionally on the basis of the names of the botanical or zoological species from which they are isolated. Such naming system provides no clue as to the structure of fatty acids. The International Union of Pure and Applied Chemistry (IUPAC) and the International Union of Biochemistry (IUB) attempted to deal with this problem by setting up two nomenclature committees, the IUB-IUPAC Joint Commission of Biochemical Nomenclature (JCBN) and the Nomenclature Committee of IUB (NC-IUB). IUPAC states definitive rules of nomenclature for organic chemistry (1960) and lipids (1978), Markely (1960) presents a historical review of chemical nomenclature, and Fletcher et al. (1974) discuss the origin and evolution of organic nomenclature. Other excellent reference sources for fatty acid classifications and nomenclatures include Fahy et al. (2005), Fasman (1989), Gunstone (1996, 1999), Gunstone et al. (1992), Gunstone and Herslof (1992), Hopkins (1972), and Robinson (1982).

II. NOMENCLATURE

According to the strictest rules of nomenclature, a chemical name must identify and describe its chemical structure unambiguously. This is done by using systematic nomenclature, and there is no

possibility of mistaken identity when this system is used. The systematic method names fatty acids solely on the basis of the number of carbon atoms and the number and position of unsaturated bonds relative to the carboxyl group(s). Substituted groups and their positions are identified. Optical activity and geometric configuration at double bonds are also designated. Systematic nomenclature will be described generally for the saturated fatty acids and then for other types of fatty acids as necessary thereafter.

It is also important to note that there are modifications to this naming system that bring novel naming systems into existence. Trivial (common) nomenclature, which includes circumstantially assigned names, for example, source names, is widely used. The English system of trivial name arose from the practice of adding the suffix “-ic” to a root indicative of the natural source or some property of the acid; for example, acetic (ethanoic) acid from the Latin word *acetum*, meaning vinegar; stearic (octadecanoic) acid from the Greek word *stear*, meaning tallow; palmitic (hexadecanoic) acid from palm oil; and oleic (octadecenoic) acid from the Latin word *oleum*, meaning oil.

Semisystematic nomenclature is often found in verbal communication and as an abbreviation in written communication. This system tries to preserve some of the structural features of systematic nomenclature, yet does so using trivial names, illustrating features that seem important for a particular purpose at the time. For example, the systematic name 2-hydroxy-*cis*-9, *cis*-12, *cis*-15-octadecatrienoic acid might become abbreviated to 2-hydroxylinolenic acid.

Also widely used is the structural system in which fatty acids are identified solely by carbon number and number of unsaturated double bonds. Morris (1961) has proposed that chain length be designated as C10, C20, and so forth, and the unsaturated double bonds be serialized. That is, either methylene-interrupted or conjugated, only the number of the carbon where the series begins will be indicated. For example, linolenic acid, or *cis*-9, *cis*-12, *cis*-15-octadecatrienoic acid, becomes C18:3 Δ 9c.

The Greek letters omega (ω) and delta (Δ) are sometimes used with special significance in naming fatty acids. Omega is often used to indicate how far a double bond is from the terminal methyl carbon irrespective of the chain length. Delta, followed by a numeral or numerals, is used to designate the presence and position of one or more double or triple bonds in the hydrocarbon chain counting from the carboxyl carbon. Thus, ordinary oleic acid is also named Δ 9-octadecenoic acid.

Another system of nomenclature in use for unsaturated fatty acids is the “ ω ” or “n” classification, and the “n” system is analogous to the “ ω ” naming system. This system is often used by biochemists to designate sites of enzyme reactivity or specificity. The terms “ ω ” and “n” refer to the position of the first double bond in the carbon backbone of the fatty acid, counting from the end opposite to the carboxy group or closest to the methyl end of the molecule. Thus, oleic acid, which has its double bond nine carbons from the methyl end, is an ω -9 (or n-9) fatty acid, and linoleic acid is an ω -6 (or n-6) fatty acid because its second double bond is six carbons from the methyl end of the molecule (or between carbons 12 and 13 from the carboxyl end). Eicosapentaenoic acid, found in many fish oils, and alpha-linolenic acid, found in certain vegetable oils, are both ω -3 (or n-3) fatty acids, which have the first double bond that exists as the third carbon-carbon bond from the terminal methyl end (ω) of the carbon chain. Also, both ω - and n-naming methods give a clear indication of the stereoisomeric species concerned; for example, *cis* C20:4n-6 and *cis* C20:4 ω -6. The first number indicates the number of carbon units, the second number refers to the number of double bonds, and the n-6 or ω -6 designation refers to the position of the last double bond. Both the “ ω ” and “n” nomenclature methods used to designate the position of the last terminal double bond are interchangeably used, however, the “n-3” designation is the proper IUPAC abbreviation. See Davidson and Contrill (1985) for a comparison of the “n” and “ ω ” naming systems.

The nomenclature of some common fatty acids using the four common naming systems is shown in Table 1.1. Of which, three systems employ the chain length and the number and position of any double bond. The first two columns show systems based on complete names and the last two columns show systems for denoting fatty acids with abbreviations.

Although the IUPAC system is unambiguous, some authors still select a nomenclature system according to their audience. Also, criteria for a suitable abbreviated terminology have been proposed but have yet to be universally adapted. Questions of which abbreviated terms are most appropriate

TABLE 1.1
Nomenclature of Some Common Fatty Acids

Names		Abbreviation	
Trivial	IUPAC	Carboxyl-Reference	n- or ω -Reference
Palmitic acid	Hexadecanoic acid	16:0	16:0
Stearic acid	Octadecanoic acid	18:0	18:0
Oleic acid	9-Octadecenoic acid	18:1 Δ 9	18:1n-9 or 18:1-9
Linoleic acid	9,12-Octadecadienoic acid	18:2 Δ 9,12	18:2n-6 or 18:2-6
Linolenic acid	9,12,15-Octadecatrienoic acid	18:3 Δ 9,12,15	18:3n-3 or 18:3-3

for representing the long and complicated chemical names will continue until an accepted system of nomenclature for individual fatty acids is agreed upon.

III. SATURATED FATTY ACIDS

The naturally occurring fatty acids can be grouped on the basis of the presence of double or triple bonds into two broad classes termed *saturated* and *unsaturated*. Most of the saturated fatty acids occurring in nature have unbranched structures with an even number of carbon atoms. They are referred to as normal alkanolic acids and may bear the prefix “*n*,” such as in *n*-hexanoic or *n*-octadecanoic. They have the general formula $R-COOH$, in which the *R* group is a straight-chain hydrocarbon of the form $CH_3(CH_2)_x$ or C_nH_{2n+1} . These acids range from short-chain-length volatile liquids to waxy solids having chain lengths of ten or more carbon atoms. Fatty acids from 2 to 30 carbons (or longer) do occur, but the most common and important acids contain between 12 and 22 carbons and are found in many different plant and animal fats. Under the systematic rules of nomenclature, the aliphatic acids are regarded as derivatives of hydrocarbons of the same number of carbon atoms ($-CH_3$ is replaced by $-COOH$). The final “e” of the corresponding hydrocarbon (alkane) is replaced by the suffix “-oic”; for example, alkane becomes alkanolic. The unsaturated fatty acids are named in a similar manner, with alkene becoming alkenolic and alkyne becoming alkynolic. The presently accepted names for the hydrocarbons are given in Table 1.2. The tables in this and the following sections are representative only, not complete. Except for the first four members of the series (meth-, eth-, prop-, but-), which have trivial names, the prefix of the name cites the number of carbon atoms.

Saturated fatty acids are also functionally divided into short- and long-chain acids and are most widely known by their trivial names. Table 1.3 lists some of the most important saturated fatty acids. Also included is a system of abbreviated nomenclature that designates chain length and degree of unsaturation; for example, 18:0 designates an 18-carbon saturated fatty acid, whereas 18:2 indicates two double bonds. The location of unsaturations as well as conformation of double bonds can also be designated; 18:2 Δ 9c, 12c designates *cis* double bonds at the 9 and 12 carbons from the carboxyl group. Similar designations will be described for hydroxy, keto, and so on.

The short-chain saturated acids (4:0–10:0) are known to occur in milk fats and in a few seed fats. Bovine milk contains butanoic acid as well as smaller amounts of 6:0, 8:0, 10:0, and 12:0 acids. Milk from the sheep and goat also contain these, but decanoic is present in larger amounts. Lauric acid (12:0) and myristic acid (14:0) are major components of seed fats of the Lauraceae and Myristiceae families, which accounts for their trivial names. Palmitic acid is the most prominent saturated fatty acid occurring in fish oils, in the milk and storage fat of many mammals, and in vegetable fats. Stearic acid (18:0) is a minor component in most vegetable fats, and its trivial name derives from the fact that it is a major component in the tallow of ruminants.

The long-chain saturated acids (19:0 and greater) are major components in only a few uncommon seed oils. Although many types of fatty-acid-containing oils are present in natural sources, only