NUTRITIONAL EVALUATION OF FOOD PROCESSING

SECOND EDITION

Edited by **ROBERT S. HARRIS, Ph.D**

and **ENDEL KARMAS, Ph.D.**

NUTRITIONAL EVALUATION OF FOOD PROCESSING

SECOND EDITION

Edited by ROBERT S. HARRIS, Ph.D.
Professor Emeritus of Nutritional Biochemistry,
Massachusetts Institute of Technology,
Cambridge, Massachusetts

and ENDEL KARMAS, Ph.D.
Associate Professor of Food Science,
Rutgers University,
New Brunswick, New Jersey

WESTPORT, CONNECTICUT
THE AVI PUBLISHING COMPANY, INC.
1975

Library of Congress Catalog Card Number: 75-25422
ISBN-0-87055-189-2

Printed in the United States of America

Contributors

L. R. BAKER, Ph.D., Associate Professor, Horticulture, Department of Horticulture, Michigan State University, East Lansing, Michigan

PETER M. BLUESTEIN, Ph.D., Thomas J. Lipton, Inc., 800 Sylvan Avenue, Englewood Cliffs, New Jersey

BENJAMIN BORENSTEIN, Ph.D., Manager, Food Industry Technical Services, Roche Chemical Division, Hoffmann-LaRoche, Inc., Nutley, New Jersey

RICARDO BRESSANI, Ph.D., Head, Division of Agricultural and Food Chemistry, Institute of Nutrition of Central America and Panama, Guatemala City, Guatemala

T. C. BYERLY, Ph.D., Consultant to the Food Industry, 6-J Ridge Road, Greenbelt, Maryland

WILLIAM K. CALHOUN, Ph.D., Chief, Nutrition Division, Food Laboratory, U.S. Army Natick Laboratories, Natick, Massachusetts

WINIFRED M. CORT, Ph.D., Group Leader, Quality Control, Hoffmann-LaRoche, Inc., Nutley, New Jersey

HENRYK DAUN, Ph.D., Assistant Professor, Food Science, Department of Food Science, Rutgers University, New Brunswick, New Jersey

JOHN W. ERDMAN, JR., Ph.D., Department of Food Science, Rutgers University, New Brunswick, New Jersey

BERNARD FEINBERG, Consultant to the Food Industry, 1188 Keeler Ave., Berkeley, California

OWEN FENNEMA, Ph.D., Professor, Food Chemistry, Department of Food Science, University of Wisconsin, Madison, Wisconsin

VERNON L. FRAMPTON, Ph.D., Research Leader, Biochemistry and Biophysics, Southern Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, New Orleans, Louisiana

ROBERT S. HARRIS, Ph.D., Professor Emeritus, Nutritional Biochemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts

NORMAN D. HEIDELBAUGH, V.M.D., M.P.H., Ph.D., U.S. Air Force Representative on the Department of Defense Food Program, U.S. Army Natick Laboratories, Natick, Massachusetts

GEORGE E. INGLETT, Ph.D., Chief, Cereal Properties Laboratory, Northern Regional Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Peoria, Illinois

IVAN D. JONES, Ph.D., Professor Emeritus, Food Science, North Carolina State University, Raleigh, North Carolina

EDWARD S. JOSEPHSON, Ph.D., Deputy Technical Director, Food Service Systems Program, U.S. Army Natick Laboratories, Natick, Massachusetts

MARCUS KAREL, Ph.D., Professor, Food Engineering and Deputy Department Head, Department of Nutrition and Food Science, Massachusetts Institute of Technology, Cambridge, Massachusetts

ENDEL KARMAS, Ph.D., Associate Professor, Food Science, Department of Food Science, Rutgers University, New Brunswick, New Jersey

JOHN. M. KROCHTA, Ph.D., Research Chemical Engineer, Western Regional Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Berkeley, California

THEODORE P. LABUZA, Ph.D., Professor, Food Technology, Department of Food Science and Nutrition, University of Minnesota, St. Paul, Minnesota

PAUL A. LACHANCE, Ph.D., Professor, Nutritional Physiology, Department of Food Science, Rutgers University, New Brunswick, New Jersey

DARYL. B. LUND, Ph.D., Associate Professor, Food Science, Department of Food Science, University of Wisconsin, Madison, Wisconsin

D. D. MAKDANI, Ph.D., Department of Food Science and Human Nutrition, Michigan State University, East Lansing, Michigan

SAMUEL A. MATZ, Ph.D., Vice President, Research and Development, Ovaltine Products, Villa Park, Illinois

OLAF MICKELSEN, Ph.D., Professor, Food Science and Human Nutrition, Department of Food Science and Human Nutrition, Michigan State University, East Lansing, Michigan

ELDON E. RICE, Ph.D., Chief Nutritionist, Research and Development Center, Swift & Co., Oak Brook, Illinois

R. THIESSEN, JR., Corporate Research Manager, Nutrition Sciences, General Foods Corporation, White Plains, New York

MIRIAM H. THOMAS, M.S., Research Chemist, Nutrition Division, Food Laboratory, U.S. Army Natick Laboratories, Natick, Massachusetts

WALTER J. WOLF, Ph.D., Research Leader, Meal Products, Northern Regional Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Peoria, Illinois

Preface to the Second Edition

The editors are indeed proud to present this Second Edition of *Nutritional Evaluation of Food Processing.* Thirty authors, who are competent in nutrition, food science, and food technology, collaborated in writing this volume. We are indebted to them for their scholarly contributions and for the time and effort which they have so unselfishly devoted to this task.

During the 15 years that have passed since the first edition was published there has been an accelerating interest in the effects of food handling and processing on the nutritional quality of prepared foods. Before 1960, farmers, food processors, and housewives were especially interested in food as a commodity and seemed only mildly interested in food quality, i.e., nutrient content. Some may find it difficult to believe that until recently the science of nutrition was seldom included in the curriculum of food scientists and food technologists; today basic and even advanced nutrition are important subjects.

An important breakthrough occurred during the 1960's when precise and rapid methods for estimating the vitamin, mineral, and amino acid contents of raw foods and food products were developed. By the use of these procedures it was soon proven that significant amounts of nutrients in processed (cooked and stored) foods were reduced, at times seriously, due to extraction into the cooking water or to destruction through chemical reactions.

The reader may be interested to learn that the first edition of *Nutritional Evaluation of Food Processing* was prompted by the results of three studies conducted at the Massachusetts Institute of Technology (Harris *et al.*, Proc. Conf. Inst. Food Technologists, 1940; Harris *et al.*, J. Lab. Clin. Med. *25*, 838, 1940; Harris and Mosher, Food Res. *6*, 387, 1940). These data led to the conclusion that a reference book concerned with the effects of food processing and food nutrients was urgently needed.

A remarkable change has taken place since then. Food scientists, food technologists, nutritional biochemists, clinical nutritionists, and dieticians are much more concerned about the beneficial and deleterious effects of food processing than ever before.

Genetically-improved food varieties are being developed by plant breeders to improve the quality of foods from plant and animal sources. Nutritionally-balanced diets are being provided for the nourishment of people of all ages, and especially those people with biomedical disorders who must avoid excess intakes or otherwise control their intake of specific nutrients or dietary factors. The federal government is now providing guidelines which will assist in the selection of more nutritious, less expensive, and more acceptable diets.

When the first edition was written, the subject was discussed in terms of commodities. In this second edition, it is discussed primarily in terms of food processing since modern food science is no longer taught in terms of food commodities.

It is our hope that this book will serve as a text and reference book and thus help readers in nutritional evaluation of food processing.

ROBERT S. HARRIS
ENDEL KARMAS

December, 1974

Preface to the First Edition

If food processing is defined to include all treatments of a foodstuff from the place of origin to the point of consumption, then more than 95% of our food is processed.

This book is concerned with the nutritional effects of the processing of foods as they proceed from garden to gullet. Most foodstuffs are not fully acceptable and must be trimmed and cooked to make them more palatable and nutritious. Some foods are contaminated with microorganisms and insects and must be treated to make them safe and acceptable. Most foodstuffs are not stable and must be milled, pasteurized, canned, refrigerated, frozen, dehydrated, and packaged so that they may be stored and transported to urban and suburban areas where most consumers work and live.

Approximately four dozen nutrients (amino acids, minerals, vitamins, calories) are required in human nutrition. These nutrients are present in a wide variety of foods. Because they are unequally distributed in various plant and animal tissues, and because they are unequally sensitive to temperature, light, air, etc., the losses in nutrients resulting from processing vary according to the type of food, process, time, and nutrient involved.

Food processing is essential if a population is to be fed. In most cases food processing causes a reduction of the nutritional value of a food. As a result of advances in the science of food and nutrition, the adverse effects of processing which formerly were unconscious are now becoming conscious. As we study the consequences of our actions, we should correct them. As we introduce new methods of processing, we should try to be aware of their consequences. The main purpose of this book is to evaluate the known effects of processing upon the nutritional values of foods, and to indicate how certain processing procedures may be altered to minimize losses in nutritional value.

It is with deep regret that I must record the death of the co-editor, Mr. von Loesecke, while this book was in preparation. It is a tragedy that the life of this able scientist and genuine friend has ended so prematurely.

I take this occasion to give abundant thanks to the authors who contributed to this book.

ROBERT S. HARRIS

February, 1960

Contents

Section V. Nutrification and Nutrient Metabolism

SECTION I

Introduction

CHAPTER 1

Robert S. Harris

General Discussion on the Stability of Nutrients

Nutrients are destroyed when foods are processed largely because they are sensitive to the pH of the solvent, to oxygen, light and heat, or combinations of these. Trace elements (especially copper and iron) and enzymes may catalyze these effects.

In Table 1.1 are tabulated the relative stabilities of the vitamins and amino acids under these various conditions. Vitamin A is stable under an inert atmosphere but rapidly loses activity when heated in the presence of oxygen, especially at higher temperatures. It is completely destroyed when oxidized or dehydrogenated. It is more sensitive to ultraviolet than to other wavelengths of light.

Ascorbic acid is fairly stable in acid solution and decomposes in light, and this decomposition is greatly accelerated in the presence of alkalies, oxygen, copper, and iron.

A 50% loss in biotin occurs when it is boiled for 6 hr in 30% hydrochloric acid or for 17 hr in 1 Normal potassium hydroxide, yet it is relatively stable in air and oxygen or when exposed to ultraviolet light. It is inactivated by agents which oxidize the sulfur atom, and by strong acids and alkalies.

Essential fatty acids isomerize when heated in alkali and are sensitive to light, temperature, and oxygen. When oxidized, they become inactive biologically and may even be toxic.

The stability of vitamin D is influenced by the solvent in which it is dissolved, but it is stable when crystals are stored in amber glass bottles. Generally, it is stable to heat, acids, and oxygen. It is slowly destroyed in foods and feeds which are slightly alkaline, especially in the presence of air and light.

The folic acid group is stable during boiling at pH 8 for 30 min, yet large losses occur during autoclaving in acids and alkalies. This destruction is accelerated by oxygen and light.

Inositol is stable during refluxing in strong hydrochloric acid or potassium hydroxide. It occurs in plants mainly in the form of phytic acid salts, and as plant and animal phosphoinositides. These complexes are broken down by phosphatases and similar enzymes. The free inositol has the highest biological value.

Vitamin K is stable to heat and reducing agents, and is labile to alcoholic alkali, oxidizing agents, strong acids, and light.

Niacin amide is partially hydrolyzed by acid and alkali, yet the resulting niacin has the same biological activity. Niacin is generally stable to air, light, heat, acids, and alkalies.

Pantothenic acid is most stable at pH 5.5–7.0, is rapidly hydrolyzed under stronger acid or alkaline conditions, and is labile to dry heat, hot acid, or hot alkalies.

p-Amino benzoic acid is only slightly destroyed by autoclaving in 6*N* sulfuric acid for 1 hr, is fairly stable in mild alkali, but is unstable in strong alkali.

Vitamin B-12 (cobalamin, etc.,) is stable to heat in neutral solution if pure, but is destroyed when heated in alkaline or acid media in crude preparations, as in foodstuffs. Choline is strongly alkaline and is slightly unstable in solutions in the presence of oxygen.

The vitamin B-6 group contains pyridoxine, pyridoxal, and pyridoxamine. Pyridoxine is stable to heat, strong alkali or acid but is sensitive to light, especially ultraviolet light, and when in alkaline solutions. Pyridoxal and pyridoxamine are rapidly destroyed by exposure to air, heat, and light. All three are sensitive to ultraviolet light when in neutral or alkaline solution. Pyridoxamine in foods is sensitive to processing.

Riboflavin is very sensitive to light, and the rate of destruction increases as the pH and temperature increase. Thus, the riboflavin of milk is rapidly lost (50% in 2 hr) on exposure to sunlight, and the resulting derivative (lumiflavin) in turn destroys the ascorbic acid in milk. It is stable to heat if in dry form or in an acid medium.

Thiamin suffers no destruction when boiled in acid for several hours, yet the loss approaches 100% when boiled at pH 9 for 20 min. It is unstable in air, especially at higher pH values, and is destroyed by autoclaving, sulfites, and alkalies.

The tocopherols are stable to vigorous boiling in acid in the absence of oxygen and are stable to visible light. They are unstable at room temperature in the presence of oxygen, alkalies, ferric salts, and when exposed to ultraviolet light. Considerable loss of tocopherols occurs in the oxidation of fats and in deep-fat frying due primarily to destruction by chemically active fatty acid derivatives formed in the fats during heating and oxidation. The esters of tocopherols are more stable than the free phenols.

Amino acids racemize in alkaline solutions, and the biological value

TABLE 1.1

STABILITY OF NUTRIENTS

Nutrient	Effect of pH: Neutral pH 7	Acid <pH 7	Alkaline >pH 7	Air or Oxygen	Light	Heat	Max Cooking Losses
Vitamins							%
Vitamin A	S	U	S	U	U	U	40
Ascorbic acid (C)	U	S	U	U	U	U	100
Biotin	S	S	S	S	S	U	60
Carotene (pro-A)	S	U	S	U	U	U	30
Choline	S	S	S	U	S	S	5
Cobalamin (B-12)	S	S	S	U	U	S	10
Vitamin D	S		U	U	U	U	40
Folic acid	U	U	S	U	U	U	100
Inositol	S	S	S	S	S	U	95
Vitamin K	S	U	U	S	U	S	5
Niacin (PP)	S	S	S	S	S	S	75
Pantothenic acid	S	U	U	S	S	U	50
p-Amino benzoic acid	S	S	S	U	S	S	5
Pyridoxine (B-6)	S	S	S	S	U	U	40
Riboflavin (B-2)	S	S	U	S	U	U	75
Thiamin (B-1)	U	S	U	U	S	U	80
Tocopherol (E)	S	S	S	U	U	U	55
Essential amino acids							
Isoleucine	S	S	S	S	S	S	10
Leucine	S	S	S	S	S	S	10
Lysine	S	S	S	S	S	U	40
Methionine	S	S	S	S	S	S	10
Phenylalanine	S	S	S	S	S	S	5
Threonine	S	U	U	S	S	U	20
Tryptophan	S	U	S	S	U	S	15
Valine	S	S	S	S	S	S	10
Essential fatty acids	S	S	U	U	U	S	10
Mineral salts	S	S	S	S	S	S	3

S = stable (no important destruction).
U = unstable (significant destruction).

of some is reduced as a result. Arginine, cystine, threonine and cysteine are partially destroyed, whereas glutamine and asparagine are deaminized by alkalies. In acid solution, tryptophan is rather readily destroyed, cysteine is partly converted to cystine, serine and threonine are partly destroyed. Phenylalanine and threonine are partially destroyed by ultraviolet light. All amino acids in foods, and especially lysine, threonine, and methionine, are sensitive to treatment with dry heat and radiations. Thus, in the roasting and toasting of cereals, legumes, and prepared dry mixtures of foodstuffs a significant reduction of the biological values of their proteins may occur.

Mineral salts are not significantly affected by these chemical and physical treatments. Some may be oxidized to higher valences by exposure to oxygen, but there is no convincing evidence that their nutritional value is affected.

In Table 1.1 are also given the limits of losses of these nutrients when the average food is cooked. More complete data on the losses of several of these nutrients in specific foods during cooking are presented in Chap. 16 and 17.

Endel Karmas

The Major Food Groups and Their Nutrient Content

Nutrients are the building blocks of the human body. Nutrients are needed for growth, to maintain and repair the body tissues, to regulate body processes, and to furnish energy for the body's functions.

The nutrients that must be supplied in the daily food to keep man in good health belong to the groups of proteins, fats, and carbohydrates, the macronutrients; and vitamins and minerals, the micronutrients. Water is also an essential part of good nutrition.

More than 50 essential nutrients have been identified, and the identification of other nutrients is not yet complete. All these essential nutrients must be present in appropriate quantities to have balanced nutrition. Thus, the nutrient composition of a food is described in terms of its content of proteins, amino acids, fats, fatty acids, carbohydrates, vitamins, mineral salts, and water.

Man acquires his essential nutrients from foods obtained from the plant and animal world. The biochemistry of plants, animals, and man have much in common. Therefore, man requires much the same nutritional building blocks as those contained in plants and animals.

Figure 2.1 illustrates the biochemistry cycle of natural foods. Growing foods and harvesting foods belong to the realm of the agricultural sciences and technology. The sun's energy combines carbon dioxide, water, and soil nutrients to produce the so-called first-stage foods as related to harvesting. These are the foods of plant origin: various vegetables, fruits, seeds, tubers, etc. Foods of animal origin are obtained mostly from herbivorous animals. For instance, domestic animals providing red meat to man are mostly herbivores. This is the second stage of man's foods. And finally, the third-stage foods, such as eggs and milk, are produced by the animals.

Natural foods from all three stages may be manufactured into other processed products within that stage. For example, a texturized soy protein still belongs to the vegetable proteins, and cheese is a milk product. It is interesting to note that proteins increase in nutritive value as the amino acids from the first-stage proteins are reassembled to the second- and further to the third-stage proteins (compare the data from National Academy of Sciences—National Research Council 1963).

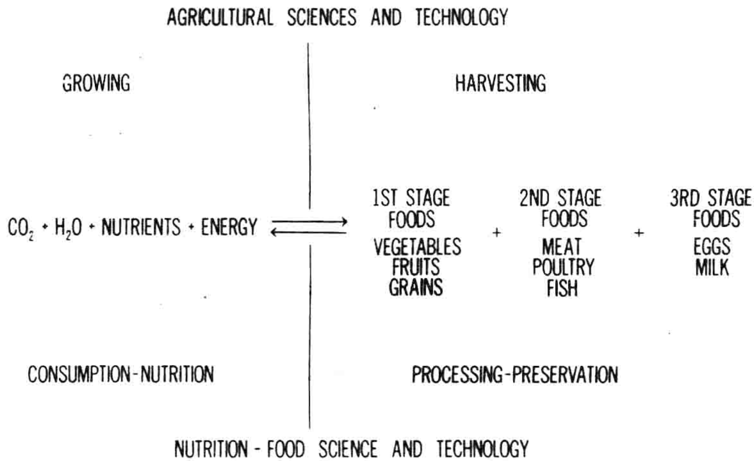

FIG. 2.1. THE RELATIONSHIPS BETWEEN THE VARIOUS LIFE SCIENCES AND THE CHEMISTRY CYCLE OF NATURAL FOODS

Natural foods are biological systems which spoil rapidly after harvest. Since man's need for food and his food harvests usually do not occur simultaneously, foods have to be preserved through processing. At times of hunger, man consumes his preserved food and starts the reverse of photosynthesis to release free energy and to obtain the essential nutrients for his biochemical needs. According to Nobel-laureate Albert Szent-Györgyi (1966), one of the basic principles of life that free energy can be preserved and stored in a foodstuff molecule and utilized when necessary.

Figure 2.1 also emphasizes the important relationship between the nutrient value of foods and food processing. Various foods serve as carriers for nutrients. Changes in nutrient levels of foods with respect to processing times and intensity are the discrete variables. The fields of nutrition as well as food science and technology deal with changes in these variables. This volume in particular concerns itself with nutritional evaluation of food processing.

Detailed data on food consumption in the United States are available from government sources (U.S. Dept. of Agr. 1974). Table 2.1 summarizes the per capita consumption of major food commodities in 1974. Foods of plant origin and foods of animal origin share about equally in American nutrition, totaling 85% of all the foods by weight. The total average per capita consumption of food in 1974 was estimated 1362 lb, which is equal to about 9 times the weight of an average man.

The available nutrient composition of natural foods in the diet in