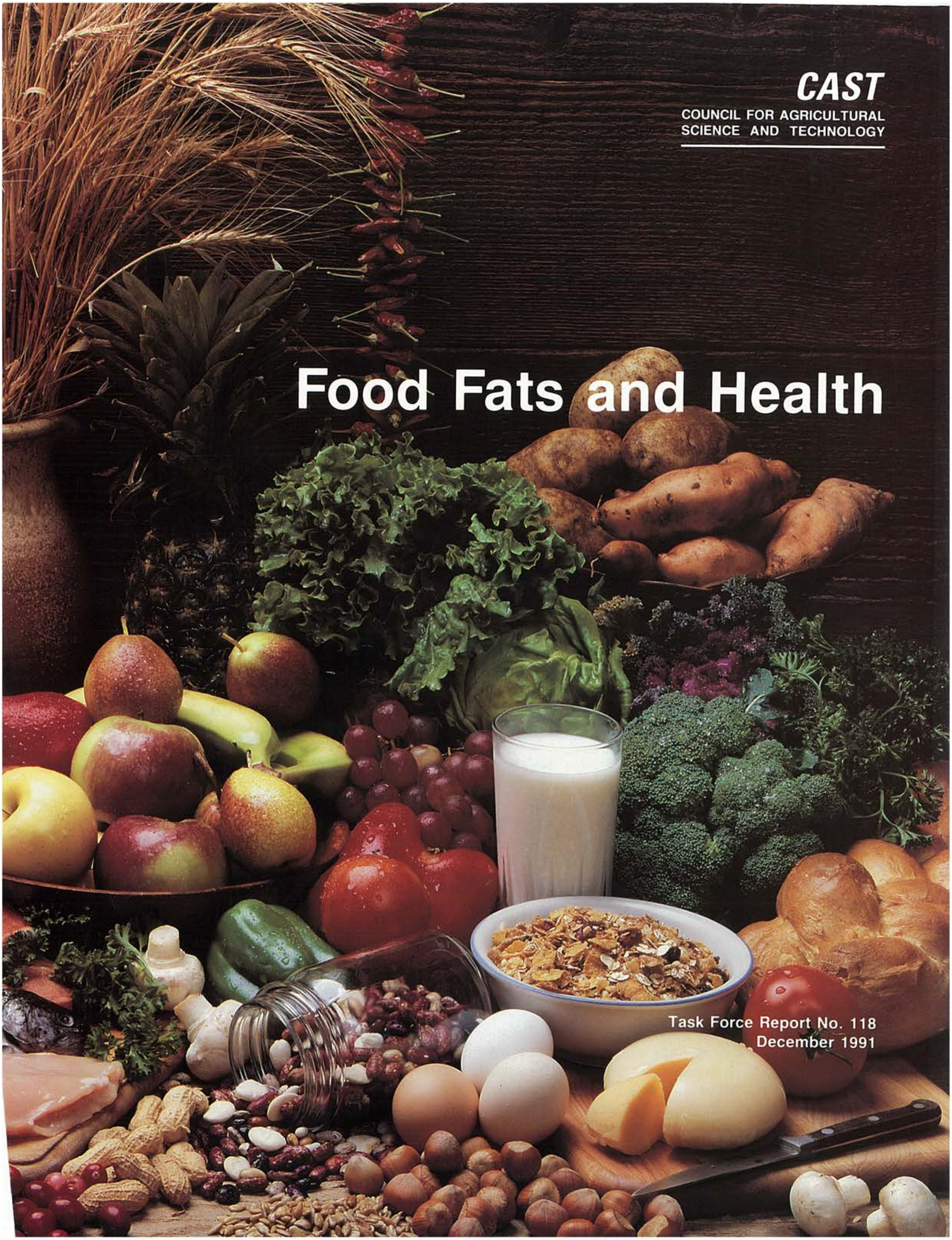

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COUNCIL FOR AGRICULTURAL SCIENCE AND TECHNOLOGY

Food Fats and Health

Task Force Report No. 118
December 1991

CAST

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Food Fats and Health

Council for Agricultural Science and Technology, Ames, Iowa 50010
Printed in the United States of America
Cover photograph by Peter Krumhardt, Madrid, Iowa
96 95 94 93 92 91 4 3 2 1

Library of Congress Cataloging-in-Publication Data

Food Fats and Health.
96 p. 28 cm. –(Task Force Report, ISSN 0194–4088 ; no. 118)
"December 1991."
Includes bibliographical references.
1. Lipids in human nutrition. 2. Fat--Health aspects. 3. Food-Fat content. I. Council for Agricultural Science and Technology. II. Series: Task force report (Council for Agricultural Science and Technology ; 118.
QP751.F64 1992
613.2'8--dc20 91-39253
ISSN 0194-4088 CIP

Task Force Report
No. 118 December 1991

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The Council for Agricultural Science and Technology (CAST) is a nonprofit organization comprised of 29 member scientific societies and many individual, company, nonprofit, and associate society members. CAST's Board of Directors is composed of 48 representatives of the scientific societies and individual members, and an executive committee. CAST provides scientific information on key national issues in food and agriculture to policymakers, the news media, and the public. As an educational organization CAST takes no advocacy positions on issues.

The primary mission of CAST is the publication of task force reports written by scientists from many disciplines. The National Concerns Committee screens proposals from all sources and recommends to the Board certain topics for approval as task force projects.

Through representatives on the CAST Board of Directors, the member societies are responsible for the policies and procedures followed in developing, processing, and disseminating the documents produced. Depending on the nature of the publication, the society representatives nominate qualified persons from their respective disciplines for participation in the preparation. Aside from these involvements, the member societies have no responsibility for the content of any CAST publication.

Careful selection of topics, diverse writing groups, and active participation by all task force members assures readers that a balanced statement on agriculturally related social, economic, environmental, energy, and health issues will result.

The authors named in each publication are responsible for the contents. Task force members serve as independent scientists and not as representatives of their employers. They receive no honoraria, but are reimbursed for expenses. CAST publishes and distributes the documents.

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The complete task force report, *Food Fats and Health,* is available for $12.00 from CAST, 137 Lynn Avenue, Ames, Iowa 50010-7197, (515) 292-2125. The 4-page Summary is $1.00. Discounts are available for quantity purchases: 6-99 copies, 25% discount; 100 or more copies, 35% discount.

Foreword

The CAST National Concerns Committee recommended to the Board of Directors that CAST prepare a report addressing issues related to food fats and health. The topic was approved by the CAST Board of Directors at the February 1989 board meeting.

Dr. Donald C. Beitz, Distinguished Professor of Animal Science and Biochemistry at Iowa State University, Ames, Iowa, was selected to serve as chair. A highly qualified group of scientists was chosen and includes persons with expertise in animal science, biochemistry, crop science, dairy science, food science, poultry science, immunology, and medicine.

All authors were responsible for writing sections of the first draft, revising all subsequent drafts, and reviewing the proofs. The CAST Executive and Editorial Review Committees reviewed the final draft. The CAST staff provided only editorial and structural suggestions and published the report. The chair and authors are responsible for all scientific content in the report.

On behalf of CAST, we thank the authors who gave of their time and expertise to prepare this report as a contribution of the scientific community to public understanding. Also, we thank the employers of the authors who made the time of the authors available at no cost to CAST. The members of CAST deserve special recognition because the unrestricted contributions they have made in support of the work of CAST have financed the preparation and publication of this report.

This report is being distributed to members of Congress, the U.S. Department of Agriculture, the Environmental Protection Agency, the Food and Drug Administration, the Agency for International Development, Office of Technology Assessment, Office of Management and Budget, media personnel, and to institutional members of CAST. Individual members of CAST may receive a copy upon request. The report may be republished or reproduced in its entirety without permission. If copied in any manner, credit to the authors and CAST would be appreciated.

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Contents

Abbreviations

AHA	American Heart Association
AID	Agency for International Development
ARS	Agricultural Research Service (USDA)
BMI	Body mass index
BST	Bovine somatotropin
C	Carbon
CAST	Council for Agricultural Science and Technology
CRGO	Competitive Research Grants Office
CSRS	Cooperative State Research Service
DAF	Days after flowering
DGAT	Diacylglycerol acyltransferase
DHA	Docosahexaenoic acid
DHHS	Department of Health and Human Services
DOC	Department of Commerce
DOD	Department of Defense
EFA	Essential fatty acid
EPA	Eicosapentaenoic acid
FASEB	Federation of American Societies for Experimental Biology
FDA	United States Food and Drug Administration
HNRIM	Human Nutrition Research Information Management System
ICHNR	Interagency Committee on Human Nutrition Research
kcal	Kilocalorie
LSRO	Life Sciences Research Office
M/S	Monounsaturated/saturated ratio
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Admininstration
NCEP	National Cholesterol Education Program
NCI	National Cancer Institute
NCRBS	National Consumer Retail Beef Study
NHLBI	National Heart, Lung, and Blood Institute
NIDDK	National Institute of Diabetes, Digestive, and Kidney Diseases
NIH	National Institutes of Health
NNMS	National Nutrition Monitoring System
NRC	National Research Council
NSF	National Science Foundation
OSTP	Office of Science and Technology Policy
PG	Prostaglandin
P/S	Polyunsaturated fatty acids to saturated fatty acids ratio
PUFA	Polyunsaturated fatty acid
RDA	Recommended Daily Allowance
SCO_2	Supercritical fluid extraction with carbon dioxide (CO_2)
SFE	Superfluid extraction
TG	Triacylglycerol (triglyceride)
TSP	Textured soy protein
USDA	United States Department of Agriculture
VA	Veterans Administration
WIC	Special Supplemental Food Program for Women, Infants, and Children

Summary

What is a healthy diet? Although some qualitative differences may exist, most nutritionists agree that a healthy diet should contain all the required nutrients and enough calories to balance energy expenditure. Unfortunately, nutrient deficiencies and excesses exist in most parts of the world. For example, caloric excesses have caused obesity to become a leading nutritional problem in the United States. Furthermore, the kind and amount of fat are dietary variables that have received much attention by consumers, scientists, and food producers because of possible relationships to human health and longevity.

Sources of Fat

Americans currently consume enough fat daily to contribute about 37% of the total caloric intake. About half comes from animals, and about half comes from plants. The major constituent of food fats is triacylglycerols, also called triglycerides, which contain a variety of saturated, monounsaturated, and polyunsaturated fatty acids. The most common fatty acids in food fats contain 16 or 18 carbon atoms. Some fats, such as milk fat, contain fatty acids with fewer carbons, and some fats, such as fish oils, contain fatty acids with 20 and 22 carbons. "Saturated" fats, such as beef fat and palm oil, contain relatively high proportions of saturated fatty acids and are usually nonliquid at room temperature. Highly unsaturated or polyunsaturated fats, such as soybean oil and fish oil, contain relatively high proportions of monounsaturated and polyunsaturated fatty acids and are liquid at room temperature.

The concentration of bovine milk fat, which is primarily triacylglycerols, in commercial fluid milk ranges from 0 to nearly 3.5%. Milk fat also is present in cheeses, yogurts, and creams in varying amounts. Cholesterol, which is in the fat portion of milk, is present at 10-15 mg/100 ml of milk. Like milk fat, triacylglycerols are the major lipid in fats of meat from all food animals. The triacylglycerols present in fat cells are located within and between muscles and around the outside of meat cuts. Although some is separated during cooking, most fat stays within the muscles and is consumed. The other depots can be removed before eating the meat. Generally, meats from ruminant animals, such as cattle and sheep, contain a greater percentage of saturated fatty acids than do meats from nonruminant animals, such as swine and poultry. Whole eggs contain about 15% total fat and about 0.6% cholesterol; nearly all of each component is located in the yolk.

Nearly half of the total fat intake of Americans is derived from plant sources. Most vegetable oils are from seeds of soybeans, palm, sunflowers, rapeseed (canola), cottonseed, peanut, coconut, olive, and palm kernel. These oils have different properties because fatty acid compositions differ. Except for palm, coconut, and palm kernel, which contain highly saturated fats, the previously listed seeds contain highly polyunsaturated fats.

Strategies for Change

Dietary recommendation to decrease food fat consumption from 37 to 30% of total caloric intake has stimulated a national emphasis to decrease fat in foods. The agricultural and food industries continue to use available technologies to alter food fats to meet this goal. Concentration of fat in milk and the fatty acid composition of the fat can be altered nutritionally and genetically. The known nutritional methods, however, are impractical or uneconomical to become a major production technology at this time. Genetic methods offer potential for change in milk fat concentration in milk and in fatty acid composition. An important emphasis of the dairy products industry is the development of acceptable dairy foods that contain lesser concentrations of fat. Low-fat milks, yogurts, cheeses, and ice creams are being marketed. Modern techniques have been developed to remove much of the cholesterol from dairy foods. Additional technological advances in product composition, especially with regard to degree of fatty acid saturation and cholesterol content, are needed to alter milk fat to a composition that is more consistent with consumer concerns and health recommendations.

Physiological age, animal species, breeds within a

species, gender, body types, nutrition, and management of meat animals can influence the amount of fat and fatty acid composition of fat in meats. Use of selective breeding programs and nutritional and management advances have resulted in markedly lower fat content of meat animals during the past few years. Moreover, cooking procedures can decrease the fat content of cooked foods. The cholesterol content of meats, which ranges from about 40 mg to about 100 mg per 100 g, is affected only slightly by nutrition and management of meat animals. Feeding cattle and sheep diets rich in unsaturated fatty acids causes only slight increases in proportions of unsaturated fatty acids in their meat. On the other hand, increasing the amount of unsaturated fatty acids in the diet of pigs and poultry will increase the proportion of unsaturated fatty acids in their meat. The fat content and fatty acid composition of processed meats can be modified according to market demands through fat substitutions, water additions, carbohydrate additions, and use of technologies for cholesterol removal.

The amount of yolk in each egg can change with genetics, age, and nutrition of the hen. In contrast, the concentration of lipids in the yolk, including cholesterol, is reasonably constant. A variety of technologies are being developed to remove the cholesterol from eggs and egg products.

The properties of vegetable oils may be altered by chemical treatments, such as hydrogenation (saturation), to increase (1) oxidative stability of the oils and (2) utilization as food components that require solid products. Increased concern over saturated fatty acids by consumers and costs of hydrogenation, however, have limited the practice of hydrogenation. Alternative approaches to changing composition of vegetable fats are needed. For example, fatty acid composition of oils can be modified by plant breeding programs to improve oxidative stability and to expand utilization of the oils. Other technologies, such as rearrangement of fatty acids on the triacylglycerols of the oils and the crystallization of the triacylglycerols, can be used to improve stability and function of the oils. As knowledge of genetic and biochemical regulation of plant oil composition increases, new technologies will result in even broader applications of vegetable oils in foods in the future.

Tailored triacylglycerols and fat substitutes have been and are being developed to provide food fats with certain advantages over traditional food fats. For example, tailored fats containing increased proportions of medium-chain fatty acids are useful fat substitutes for people with insufficient fat-digesting enzymes. Water-based gels or emulsions of specific carbohydrates and proteins can replace traditional fats in food emulsions. "Zero"-calorie fat substitutes with taste and texture of traditional fats are being developed.

Health Implications

Genetics, diet composition, and other environmental factors contribute to development of cardiovascular disease, obesity, cancer, and a variety of other diseases of humans. Diet composition is one factor that can be altered to possibly change the rate of disease development. Much research, however, remains to be completed before scientists can describe reliably and predict impacts of specific dietary components, such as amount and type of fat and cholesterol, or their interactions on human disease.

Cholesterol is a necessary compound of every living animal cell and thus is a natural constituent in foods derived from animals. Although the effect of typical dietary cholesterol intake on blood cholesterol concentration in humans is usually minimal, the relationship of blood cholesterol to cardiovascular disease development has stimulated much interest by consumers in dietary cholesterol.

Intake of saturated fat, however, seems associated positively with blood cholesterol concentration, and thus saturated fats are considered a major risk factor for heart disease. Replacement of saturated fat in the diet with polyunsaturated fat frequently results in decreased blood cholesterol concentration and thus assumedly lesser risk for heart disease. More recent research, however, has demonstrated that all dietary saturated fatty acids are not equivalent with regard to effects on blood cholesterol concentration in humans. More specifically, myristic and palmitic acids seem to increase cholesterol concentrations, whereas stearic and the shorter chain saturated fatty acids seem to cause no change, like the monounsaturated fatty acids, in their effect on plasma cholesterol concentrations.

High blood pressure is a risk factor in heart disease development. Most studies indicate that increasing the ratio of polyunsaturated to saturated fat in the diet or decreasing the fat content of the diet tends to decrease blood pressure in hypertensive people. The omega-3 polyunsaturated fatty acids, such as those in fish oils, seem to decrease blood pressure.

Obesity remains a major nutritional problem in America. Because fat contains more than two times more calories than do carbohydrates and proteins, dietary fat is of major concern in obesity. The balance of total caloric intake and energy output determines obesity development. Thus, complex interactions among taste properties of dietary fats and metabolic factors and genetic background of the consumer determine the extent to which dietary consumption contributes to obesity.

Dietary constituents, such as fat, come under intense scrutiny along with viruses, radiation, and environmental chemical carcinogens as contributors to human cancer. Several epidemiological studies indicate that dietary fat intake was correlated positively with mortality rates as a result of breast and colon and, to a lesser extent, ovarian, prostate, and pancreatic cancers. Such epidemiologic studies with humans and results from animal studies have stimulated laboratories and clinics around the world to accelerate research on deciphering the alleged connection between dietary fat and cancer.

Only recently have scientists noted that dietary fat influences the immune systems of people. A deficiency of essential fatty acids decreases host immune status as well as function of immune cells. Likewise, high concentrations of fat suppress the immune system. In contrast, lower fat diets improve immune function. The omega-6 polyunsaturated fatty acids as in vegetable oils seem to suppress immune function, whereas the omega-3 polyunsaturated fatty acids as in fish oils do not decrease and in some cases enhance immune function.

Conclusion

The American diet contains about equal portions of fat from plant and animal sources. Because of recommendations to decrease consumption of total fat, saturated fat, and cholesterol, the agricultural and food industries are responding by redesigning fresh and processed foods so that consumers can more readily meet current nutritional recommendations without altering kinds of foods consumed. These responses are occurring because of the alleged association of food fats with a variety of human diseases, such as cardiovascular disease, cancer, and obesity. Much research remains to be done to more clearly define the possible associations between food fats and health, to develop technologies for making appropriate changes in food composition, and to describe the physiological and biochemical mechanisms for the effect of food fats on health. In the meantime, Americans would be prudent to follow current recommendations with regard to amount and type of food fats to be eaten.

1 The Healthy Diet

Summary

There is considerable confusion among consumers about the role of fat in the diet. Fats are commonly, and incorrectly, referred to as unsaturated or saturated. The fact is that fats differ in the proportions of polyunsaturated, monounsaturated, or saturated fatty acids and therefore are not either saturated or unsaturated.

Farmers and food processors have a direct stake in how consumers perceive the relationship between fat, health, and taste.

Consumer preferences for milk indicate the relationship between fat content and desirability. Most consumers understand the differences between whole, 2%, 1%, and skim milk. Sales of 2% milk, milk containing an intermediate amount of fat, have increased dramatically in recent years as consumers seek ways to limit fat intake without sacrificing flavor.

The best general recommendation is still to decrease total fat in the diet, and to decrease energy intake. It is also best to obtain fatty acids from a balanced intake of a variety of foods, including animal products.

Figure 1.1. **Many nutritious, appetizing and affordable food choices are available to the U.S. consumer. Photograph courtesy of the U.S. Department of Agriculture.**

The Healthy Diet

A healthy diet should contain all the required nutrients and enough calories to balance energy expenditure. A healthy diet also should be appetizing and affordable. With our abundant supply of food at affordable prices, the central issue for many Americans is to balance energy intake with energy expenditure (Figure 1.1). It is more difficult to make enlightened food choices to maintain that balance with more than 10,000 food items on grocery shelves and with the increased use of convenience foods.

Obesity is now the leading nutritional problem in America, and most of us must carefully monitor caloric intake to maintain a desirable weight. Because 3,600 kilocalories (kcal) are required to increase body weight by one pound, a person whose recommended intake was 2,000 kcal per day would gain one pound in a year by consuming just ten more calories a day.

Many studies have shown the adverse effects of obesity, and more Americans seem to be cognizant of the health risks related to obesity. One long-term study (1959 to 1972) (Lew and Garfinkel, 1979) (Figure 1.2), which involved more than 750,000 men and women, based average weights on heights, thus avoiding the issue of what is an ideal weight by height. For women who were 20% above average weight for height, deaths from all causes were 1.29 times greater than average. Death rates from all causes were approximately two times normal for those who were over 40% overweight. Diabetes, especially for women, had serious consequences for those who were obese. Death rates were 3.34 times normal for diabetics 20% overweight, and 7.9 times normal for those weighing 40% or more than average. Mortality due to digestive diseases, cerebral vascular diseases, and even cancer also increased among those who were overweight.

Americans' expanding appetites for beverages that contain calories but few other nutrients hamper efforts to control obesity while maintaining a balanced diet. Enough soft drinks are produced in the United States to provide every American with 200 kcal a day (National Restaurant Association, 1986). Likewise,

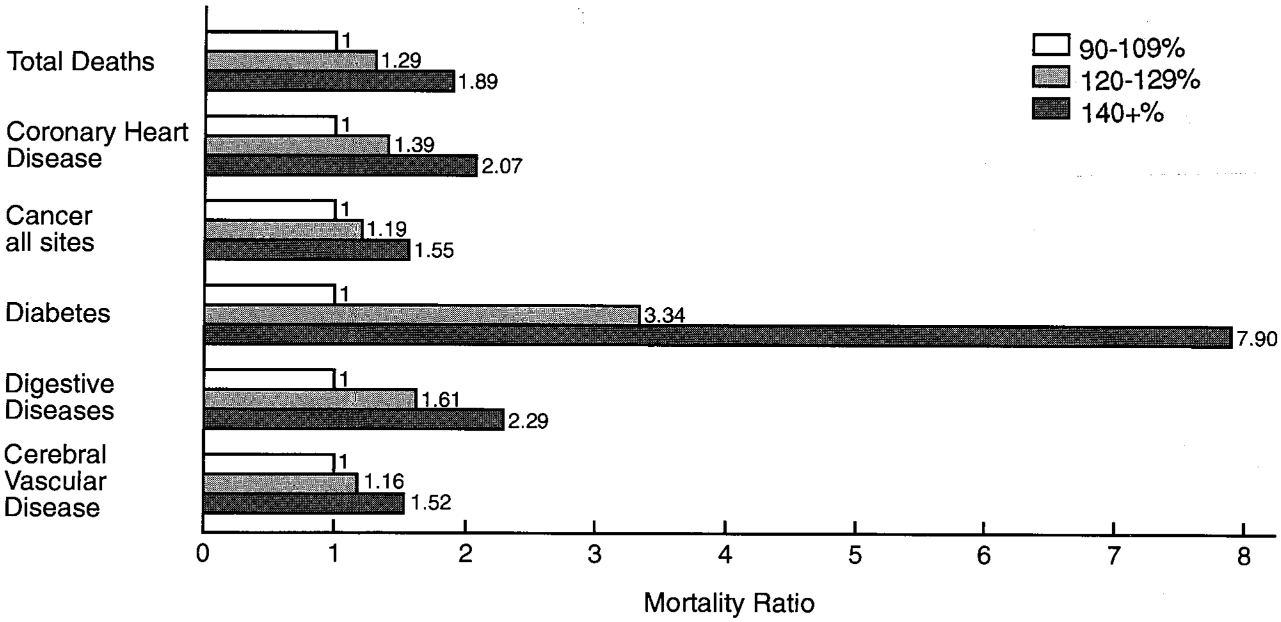


Figure 1.2. Mortality ratios for all ages of females as a function of body weight (Lew and Garfinkle, 1979).

alcoholic beverages, if evenly distributed to everyone over 14 years of age, would provide 150 kcal a day (Windham et al., 1983). These two beverages, which provide few nutrients, account for about 17% of daily caloric recommendations. Per capita production of soft drinks is increasing.

The nutrient requirements of humans are published periodically by the Food and Nutrition Board of the National Academy of Sciences (1989) as the Recommended Dietary Allowances (RDA) that dietitians and others use to evaluate diet quality. The nutrient deficits of most concern are iron, zinc, calcium, vitamins B_6 and folacin (U. S. Department of Agriculture, 1986). The inadequate intake of iron by children and of iron and calcium by premenopausal women is of particular concern. Iron is assimilated easily from lean meat, as are other trace minerals and vitamins including vitamin B_6. Milk and many milk products are good sources of calcium and vitamin A.

Average daily sodium chloride or salt consumption of 10 or 12 g is far greater than the three or 4 g suggested by the RDA and more than ten times the actual requirement. The 10th edition of the RDA makes minimal reference to fat, cholesterol, and sugar. The RDA for a reasonable amount of fat is 30% of total daily caloric intake but does not address cholesterol intake (National Academy of Sciences, 1989). Many recent publications of varying credibility have attempted to provide recommendations for cholesterol intake, and some have provided inaccurate or confusing information about acceptable fat and cholesterol intakes.

For instance, the American Heart Association (1986) published recommendations that allowed the consumption of only 100 mg of cholesterol with each 1,000 kcal of energy but permitted the consumption of 15% of calories from alcoholic beverages. This advice failed to consider that Americans obtained 10% of calories from soft drinks. Many nutritionists realize how difficult it is to balance a diet according to these recommendations, which only served to confuse the health conscious public (American Heart Association, 1988; Cleveland et al., 1987).

The recommendations concerning fat are no less confusing. Most recommend consuming less than 30% of calories as fat, but many consumers are uncertain about the type of fats, especially the specific fatty acids, to consume.

Most fats in foods are triacylglycerols that contain three fatty acids linked as ester bonds to the hydroxyl groups of glycerol. These three fatty acids may differ in their degree of saturation, chain length, or other properties, and it is chemically inaccurate to refer to a fat as saturated or unsaturated, as is done commonly by the media or even some nutrition professionals. The fatty acids in a fat are either saturated, monounsaturated, or polyunsaturated, and their chemical characteristics or their metabolism and hence their nutritional properties vary accordingly. For example, saturated fatty acids with 12 (C_{12}), 14 (C_{14}), and 16 (C_{16})

carbon atoms seem to be metabolized differently than fatty acids with 18 (C_{18}) carbon atoms (Bonanome and Grundy, 1988). In some diets, the C_{12}, C_{14}, and C_{16} saturated fatty acids may raise blood cholesterol, whereas C_{18} saturated fatty acids may have little effect or actually lower blood cholesterol.

Except for butterfat, the major saturated fatty acids in most animal fats are palmitic (C_{16}) and stearic acids (C_{18}) (Table 1.1). In addition to these saturated fatty acids, milk fat also contains significant amounts of short-chain fatty acids.

Oleic acid, a major fatty acid component of animal fats, may have hypocholesterolemic effects in humans, and moderate amounts are not considered to be undesirable.

The two fats that contain the large amounts of C_{12}, C_{14}, and C_{16} saturated fatty acids are palm kernel oil and coconut oil. Animal fats contain a broad spectrum of fatty acids, including saturated, monounsaturated (typically), and polyunsaturated fatty acids; C_{18} fatty acids are the predominant type. Thus, it is completely inaccurate to state that all animal fats are high in saturated fatty acids.

The type and amount of fat and the amount of cholesterol in the diet are emphasized often because these dietary constituents presumably affect blood cholesterol concentration. For most people, blood cholesterol changes very little in response to the amounts of these components contained in the mixed foods consumed in American diets. When energy consumption exceeds expenditures, all calories from fat, carbohydrate, and protein may be converted either to fatty acids or to blood cholesterol. Normally, the body synthesizes several times more cholesterol than is consumed.

The dietary measures that seem to be the most effective in decreasing blood cholesterol when desirable are (1) restricting caloric intake to balance expenditures of energy, (2) decreasing total fat in the diet, (3) decreasing intake of the C_{12}, C_{14}, and C_{16} saturated

Table 1.1. Fatty acid composition of selected fats and oils, expressed as weight percentage of total fatty acids[a]

	Fatty acid							
	Saturated				Monounsaturated		Polyunsaturated	
Fat or Oil	$\leq C_{10:0}$	$C_{12:0}$, $C_{14:0}$, $C_{16:0}$	$C_{18:0}$	Other	$C_{16:1}$, $C_{18:1}$	Other	$C_{18:2}$, $C_{18:3}$	Other
Animal Fat								
Beef tallow	0.1	28.9	21.6	3.0	42.1	1.1	2.8	0.4
Butter fat	9.2	41.0	12.5	2.5	30.1	1.2	3.4	0.1
Chicken fat	—	24.7	6.4	0.3	48.1	0.3	20.2	—
Cod liver oil	—	3.2	3.7	1.2	34.6	14.6	2.4	34.9
Egg yolk	—	26.1	9.9	—	49.9	—	14.7	—
Herring oil	—	8.0	2.2	0.5	35.2	21.9	2.2	29.0
Lard (pork)	0.1	26.4	12.3	0.9	48.2	1.6	10.0	0.5
Mutton tallow	0.2	29.1	24.5	3.6	35.8	1.1	5.3	0.4
Salmon oil	—	15.1	3.8	1.5	42.5	18.5	2.4	12.7
Turkey fat	—	26.0	10.0	0.5	26.5	0.4	21.0	13.5
Plant Fat								
Cocoa butter	—	25.9	34.5	1.1	35.6	—	2.9	—
Coconut oil	14.9	74.5	2.5	0.1	6.5	—	1.5	—
Corn oil	—	12.2	2.2	0.1	27.6	—	57.9	—
Olive oil	—	13.7	2.5	0.9	72.3	—	10.6	—
Palm kernel oil	8.2	73.6	2.4	0.1	13.7	—	2.0	—
Palm oil	—	46.5	4.7	0.2	38.9	—	9.7	—
Rapeseed oil (low erucic)	—	3.9	1.9	1.0	64.3	1.0	27.9	—
Soybean oil	—	11.1	4.0	0.4	23.5	—	61.0	—
Sunflower seed oil	—	7.5	4.7	0.4	18.7	—	68.7	—

[a]Fats and oils are listed from most to least saturated. The numbers in the column headings indicate the length of the carbon chain of individual fatty acids and the number of double bonds. For example, a 10-carbon-chain fatty acid without double bonds is expressed as $C_{10:0}$.

Sources: Adapted from Van Den Bergh Food Ingredients Group's *Typical Compositions and Chemical Constants of Common Edible Fats and Oils.* 1970. Wayne, New Jersey and C. Lentner (Ed.). 1981. p. 264. In *Geigy Scientific Tables.* 8th rev. ed. Vol. 1. CIBA-GEIGY Corp., Basel, Switzerland.

fatty acids, and (4) increasing intake of polyunsaturated fatty acids (Council for Agricultural Science and Technology, 1987). However, the polyunsaturated fatty acids are rather chemically reactive and potentiate cancer in test animals (Cohen, 1987). For this reason, polyunsaturated fatty acids should not constitute more than one-third of the fat calories.

The principal reason for most of us to restrict fat intake is to decrease intake of calories simply because a gram of fat contains nine kcal, whereas a gram of carbohydrate or protein contains four kcal.

Americans have been advised by many scientists, nutritionists, and clinicians to eat less fat to decrease their risk of coronary heart disease. This recommendation is based on evidence that a decrease in fat intake, especially saturated fat, will decrease serum cholesterol concentration. Also, decreased fat intake may decrease mortality from a variety of cancers. The follow-up practical question is this: How much longer will Americans live if they decrease their fat intake significantly? One such estimate has been made by Browner and colleagues (1991). According to this study, if Americans decrease their average of 37% of energy intake as fat to 30%, an increase in average life expectancy of 3 to 4 months would occur. Additional studies are needed to verify whether this estimated benefit is accurate.

2 How to Meet Low-Fat Diet Recommendations

Summary

Lower fat diets can be achieved easily without changing the foods typical of the United States or of food preferences. Diets containing about 25% energy from fat and having a P/S ratio (polyunsaturated fatty acids to saturated fatty acids) of about 1.0 proved to be more healthful than the typical diet of the United States, which contains about 37% of energy from fat.

Fats

The current recommendation for the total fat content of the American diet is 30% of energy. The recommended proportions of saturated, monounsaturated, and polyunsaturated fatty acids are 10, 10, and 10% of energy, respectively. The major modification of an experimental diet to decrease fat intake involved the careful trimming of visible fat from meats, decrease of consumption of fat from sausages, and the consumption of low-fat dairy products (Iacono et al., 1975). Intramuscular fat accounts for about 2 to 6% of the triacylglycerol content of meat and is within the recommended limits of energy derived from the saturated fat of the diet. For example, the contribution of saturated fat from 182 g of meat was 14 g per day for a person consuming 2,800 kcal. This would contribute 4.5% of calories from saturated fat from meat, which is well within the 6.1% of calories for the experiment cited. The contribution of saturated fat from low-fat dairy products represented about 0.5% of calories per day, or about one-ninth the contribution from meat. There are a number of low-fat dairy products on the market, particularly skim milk, 1%, or 2% fluid milk, which are low enough in fat so that one can decrease the amount of dietary saturated fat to less than 10% of energy without great difficulty. To decrease the total saturated fat content of the diet, it is also necessary to avoid vegetable fats, such as palm, cocoa, and coconut oils, that contain highly saturated fatty acids. To achieve an intake of polyunsaturated fatty acids (PUFA) equivalent to 7 to 10% of total energy intake, it is necessary to supplement the diet with oils and margarines containing high ratios of PUFA. Common seed oils, such as corn, safflower, and sunflower, contain primarily linoleic acid (ω-6 fatty acids) and very small amounts of α-linolenic acid (ω-3), whereas oils, such as soybean and rapeseed, contain α-linolenic (ω-3) as well as higher ratios of ω-6 fatty acids (see Table 3.1 in Chapter 3). Currently, there is considerable interest in the ω-3 series of fatty acids present in foods (linolenic, eicosapentaenoic, and docosahexaenoic acids). The daily intake of ω-3 fatty acids only can be estimated at the present time because of the limited data available. Fish, particularly high-fat fish, are an excellent source of eicosapentaenoic and docosahexaenoic acids. It is important to include fish in the diet because it is a good source of protein and is generally low in saturated fat, particularly low-fat fish containing 1% or less fat.

Carbohydrates

In formulating a low-fat diet where the fat is decreased from about 37% of total energy to 30% and where carbohydrate, in the form of fruits, vegetables, and grains, is substituted for fat, the carbohydrate content of the diet is increased by about 15%. By this maneuver, the fat content of a diet containing about 2,500 kcal can be decreased by about 42 g and the carbohydrate content of the diet can be increased by about 94 g. Because the carbohydrate concentration in fruits, vegetables, and certain grains is usually low as a consequence of their high water content, the quantity of food consumed for these categories of foods is greater than the amounts usually consumed in higher fat foods. But even more important, the benefits of increasing dietary carbohydrate is the improvement in the nutrient content of the diet, particularly the vitamins and minerals, and an improvement in fiber intake by careful selection of foods (Dougherty et al., 1988).

Protein

Because the fats were trimmed carefully from meats and the fat in dairy products was decreased in the recommended diets, the high quality protein sources of the typical U.S. diets were accentuated. Moreover, vitamins and minerals in these animal protein sources are equivalent to 25 to 40% of the daily requirements for the micronutrients.

Animal protein sources represent the major contributor of dietary cholesterol. Although lean meats contain 40 to 100 mg of cholesterol per 100 g, meats can be eaten in amounts usually consumed in the Western diet without an excessive intake of cholesterol. Consumption of eggs from chickens may need to be limited to maintain less than 300 mg of cholesterol intake per day because each egg contains 200 to 225 mg of cholesterol. Low-fat dairy products contribute little cholesterol to the diet and therefore are of no great concern on the basis of cholesterol content.

Vitamins and Minerals

The vitamin and mineral content of the diet usually is improved as a consequence of decreasing fat and substituting carbohydrate for the fats. This is well described in a recent Finnish study and a controlled Metabolic Research Unit study where the intake of fruits, vegetables, and grains increased, which resulted in an increase in vitamin and mineral content of the diet (Pietinen et al., 1984). Consumption of empty calories from alcohol and sugar is of concern, but the influence of fat on the nutrient density of the diet is even more alarming.

3 Nomenclature of Food Fats

Summary

The major constituent of food fats is triacylglycerols. Other constituents include phospholipids, glycolipids, and waxes. Cholesterol and cholesteryl esters are present in animal-derived fats. Fatty acids, which may be saturated or unsaturated, are usually esterified to glycerol to form triacylglycerols and contain 16 or 18 carbons, although milk fat contains shorter chain fatty acids and fish oils contain longer chain fatty acids. Fats that are liquid at room temperature are rich in unsaturated fatty acids and are often called unsaturated fats, whereas those that are solids at room temperature are rich in saturated fatty acids and are often called saturated fats.

Introduction

Fat is a term frequently and broadly used by nutritionists and food scientists to refer to the triacylglycerol-rich fraction of foods. Through common use, fat also refers to adipose tissue of an animal body and the extractable oil from a plant crop or animal body. Oils usually refer to food fats that are liquid at room temperature and are usually of plant origin. Often the terms fat and lipid are used interchangeably, but when fat refers to adipose tissue, then fat contains lipids, water, proteins, and other constituents. Adipose tissue consists of fat cells in a matrix of connective tissue. In this publication, the term "food fats" will be used broadly and will refer to those lipid-rich fractions derived from or present within plants or animals that are used for human food.

Lipids are a group of compounds related to fatty acids and sterols that are relatively insoluble in water and soluble in nonpolar solvents, such as ether and chloroform. Lipids to be discussed in this chapter include the following compounds:

1. Fatty acids
2. Triacylglycerols
3. Phospholipids (glycerophospholipids and sphingophospholipids)
4. Glycolipids (glycosphingolipids)
5. Waxes
6. Cholesterol

Other lipids include vitamins A, D, E, and K.

Fatty Acids

Fatty acids are long-chain hydrocarbons with a carboxyl group at one end and a methyl group on the other end (Table 3.1). They are unbranched and usually have an even number of carbon atoms. Very low amounts of odd-numbered carbon chains of fatty acids, however, are found in adipose tissue of ruminants. The chains of fatty acids vary in length from 4 to 24 carbon atoms, but, in meat animal species, fish, and vegetable fats and oils, they generally range from 14 to 22 carbons. Fatty acids with carbon lengths of 16 and 18 predominate in meat and vegetable oils, whereas in some species of fish, fatty acids with carbon lengths of 18 to 22 predominate. Milk fat from ruminants contains significant amounts of fatty acids having 4 through 12 carbons as well as the longer chain acids. Coconut oil contains significant quantities of fatty acids with 10 and 12 carbons.

The long carbon chains of the fatty acids may contain only single bonds between adjacent carbons, in which case they are fully saturated with hydrogen atoms and are known as the saturated fatty acids (e.g., palmitic and stearic acids in Table 3.1). In other carbon chains, one or more double bonds appear between adjacent carbon atoms, and, because they are not fully saturated with hydrogen atoms, they are called unsaturated fatty acids (see oleic acid with a double bond between carbons 9 and 10 in Table 3.1). The fatty acids with one double bond are called monounsaturated fatty acids, and those with two or more double bonds are referred to as polyunsaturated fatty acids. The position of the double bond(s) may be indicated by the symbol delta (Δ), which for oleic and palmitoleic acids is Δ^9. Thus, the double bond is located between carbons 9 and 10 of the chain for these two fatty acids (Table 3.1). The location of the double bonds for the other fatty acids present in the lipids of food fats is shown in Table 3.1.

Table 3.1. Common fatty acids in food fats

Symbol	Common name	Structure
Saturated fatty acids		
C_4	Butyric acid	$CH_3(CH_2)_2COOH$
C_6	Caproic acid	$CH_3(CH_2)_4COOH$
C_8	Caprylic acid	$CH_3(CH_2)_6COOH$
C_{10}	Capric acid	$CH_3(CH_2)_8COOH$
C_{12}	Lauric acid	$CH_3(CH_2)_{10}COOH$
C_{14}	Myristic acid	$CH_3(CH_2)_{12}COOH$
C_{16}	Palmitic acid	$CH_3(CH_2)_{14}COOH$
C_{18}	Stearic acid	$CH_3(CH_2)_{16}COOH$
Unsaturated fatty acids		
$C_{16:1}$	Palmitoleic acid	$CH_3(CH_2)_5CH=CH(CH_2)_7COOH$
$C_{18:1}$	Oleic acid	$CH_3(CH_2)_7CH=CH(CH_2)_7COOH$
$C_{18:2}$	Linoleic acid	$CH_3(CH_2)_4(CH=CHCH_2)_2(CH_2)_6COOH$
$C_{18:3}$	Linolenic acid	$CH_3CH_2(CH=CHCH_2)_3(CH_2)_6COOH$
$C_{20:4}$	Arachidonic acid	$CH_3(CH_2)_4(CH=CHCH_2)_4(CH_2)_2COOH$
$C_{20:5}$	Eicosapentaenoic acid	$CH_3CH_2(CH=CHCH_2)_5(CH_2)_2COOH$
$C_{22:6}$	Docosahexaenoic acid	$CH_3CH_2(CH=CHCH_2)_6CH_2COOH$

The presence of a double bond in the fatty acid enables the molecule to maintain two different configurations. In one configuration, the molecule is folded back on itself at the double bond. This is the cis form. In the other configuration, the fatty acid molecule is extended fully to its maximal length at the double bond. This is the trans form of the molecule (Figure 3.1). The unsaturated fatty acids in food fats are predominantly those of the cis form. Fatty acids of the trans form occur in small amounts in fats derived from ruminants, but relatively large amounts are present in hydrogenated vegetable oils, such as shortenings and margarines.

The abbreviation system of the fatty acids universally used is as follows: the carbon atoms are indicated by C, which is followed by a subscript indicating the number of carbons in the chain, e.g., C_{16}. Additionally, the number of double bonds in the fatty acid also is included in the subscript. A colon is inserted between the carbon number and the number of double bonds. Thus, $C_{16:0}$ is 16 carbon fatty acids with no double bonds, and $C_{20:4}$ has 20 carbon atoms in the chain with four double bonds. This denotation for fatty acids will be used throughout this report. The fatty acids and some of their characteristics are presented in Table 3.1.

Three classifications of unsaturated fatty acids predominate in food fats, namely ω-9, ω-6, and ω-3 acids. These families also are referred to as n-9, n-6, and n-3 fatty acids, but the ω designation will be used here to indicate the position of the last double bond. Thus, these double bonds are at the 3rd, 6th, or 9th carbon from the methyl group end. Palmitoleic ($C_{16:1}$) (an ω-7 fatty acid) is the only exception to these three families, which are present in food fats. The polyunsaturated fatty acids are composed of the ω-3 and ω-6 acids. Linolenic, eicosapentaenoic, and docosohexaenoic acids are ω-3 fatty acids. The latter two ω-3 fatty acids are especially abundant in the lipids of fish.

The only ω-3 fatty acid present in the lipids of other foods above trace amounts is linolenic acid. This ω-3 fatty acid ($C_{18:3}$) is most abundant in plant seed oils, but is present to a much lesser extent in leafy vegetables and animal fats. Animals, including man, can convert linolenic acid to longer chain, more highly unsaturated fatty acids and yet preserve the ω-3 structure. The principal fatty acids resulting from this elongation and desaturation of linolenic acid are the polyunsaturated ω-3 fatty acids $C_{20:5}$ and $C_{22:6}$. The content of these two fatty acids in the lipids of meat animals other than fish are low and marginally detectable.

De novo synthesis of fatty acids in plants and animals terminates with the saturated 16 carbon fatty acid called palmitic acid. Subsequently, the palmitic acid may be elongated by a separate metabolic pathway. In addition, desaturase enzymes desaturate fatty acids at several positions in the chain. The desaturase activity varies between plant and animal species. Animals cannot desaturate beyond the Δ^9 position of the carbon chain, whereas plants have the enzymes to desaturate at positions Δ^{12} and Δ^{15}. Thus, animals have a dietary requirement for linoleic and linolenic acids. Enzyme complexes, however, occur in animal cells that desaturate at Δ^5 if there is a double bond at the Δ^8 position or at Δ^6 if there is a double bond at the Δ^9 position. These enzymes are different from the Δ^9 desaturase. The major polyunsaturated fatty

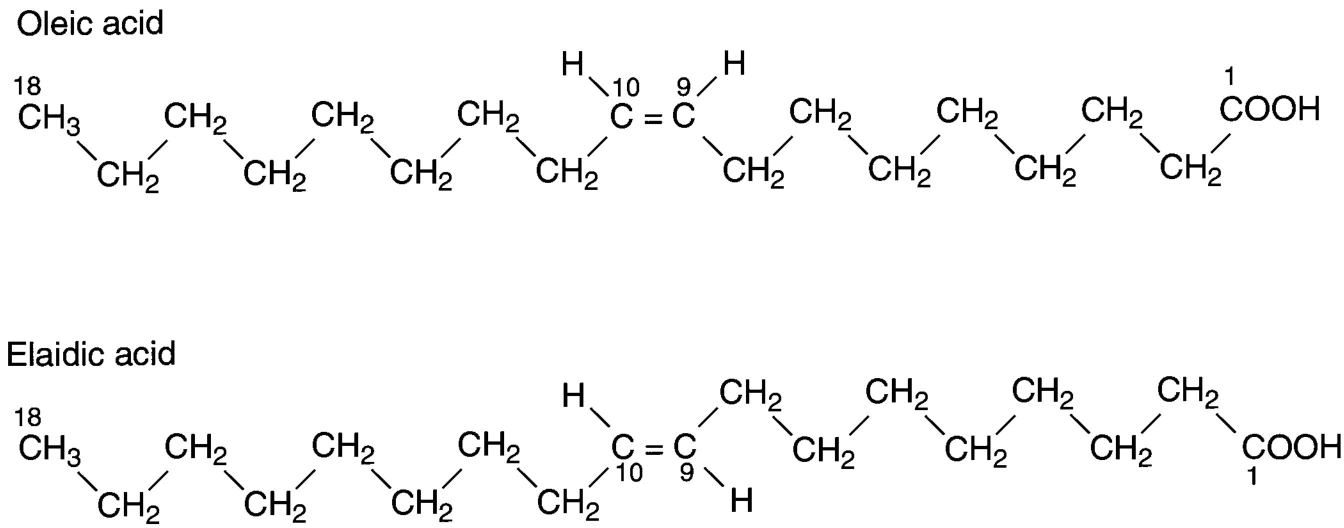


Figure 3.1. Geometric isomers of $C_{18:1}$ fatty acid. Oleic acid is the cis form; elaidic acid is the trans form.

acids of animals are either derived from the diet, especially in nonruminants, or from desaturation and elongation of 18:2 $\Delta^{9,12}$, 18:3 $\Delta^{9,12,15}$, or 20:4 $\Delta^{5,8,11,14}$. The elongation of C_{16} and C_{18} fatty acids to yield the C_{20} to C_{24} acids occurs by enzymatic addition of two-carbon units. The synthesis of arachidonic acid ($C_{20:4}$) from linoleic acid ($C_{18:2}$) illustrates the principle by which polyunsaturated fatty acids are made in animals.

Triacylglycerols

The fatty acid moieties in foods are not present in the free form but are combined by ester linkage to a three-carbon alcohol called glycerol to form triacylglycerols or triglycerides (Figure 3.2). Each fatty acid is combined by ester linkage to one of the alcohol groups of glycerol. Thus, glycerol may be esterified with one, two, or three fatty acids, giving rise to mono-, di-, or triacylglycerols, respectively. Triacylglycerols are the predominant form of all lipids associated with food fats. For example, over 98% of the fatty acids in meats, fish, and vegetable oils are in triacylglycerols. Nearly all of the remaining fatty acids also are esterified components of the phospholipids, waxes, or cholesterol, which will be discussed later. Triacylglycerols may contain several combinations of the fatty acids. If all three of the fatty acids in a triacylglycerol are the same, then it is called a simple triacylglycerol. If two or more fatty acids differ, it is called a mixed triacylglycerol, which predominates in food fats. In summary, triacylglycerols differ according to the type and placement of the three fatty acids on the glycerol and are the primary storage form of lipids in the animal body and of many plant seeds, such as soybeans.

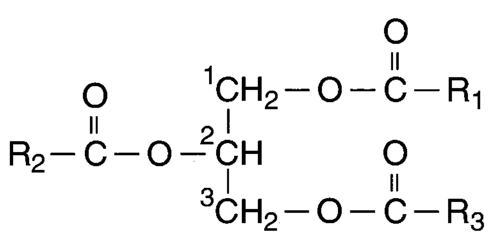


Figure 3.2. Structure of a generalized triacylglycerol. R_1, R_2, and R_3 represent three fatty acids.

Phospholipids

Glycerophospholipids and sphingophospholipids are the two types of phospholipids found in food fats. Glycerophospholipids, which are the major phospholipids in food fats, contain two fatty acids esterified with two of the alcohol groups of the glycerol molecule (Figure 3.3). The third alcohol group of glycerol is esterified with phosphoric acid, which, in turn, is esterified with another alcohol, such as ethanolamine, choline, inositol, the hydroxy amino acid called serine, glycerol, or phosphatidylglycerol. Glycerophospholipids are named according to the identities of these alcohol moieties. For example, the choline-containing ones are called phosphatidylcholine.

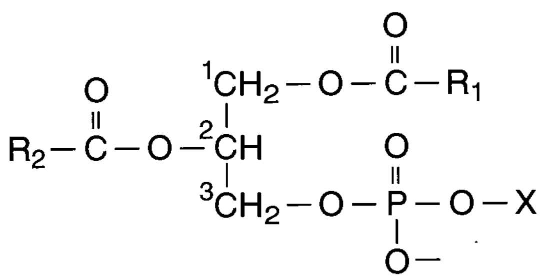


Figure 3.3. Generalized structure for a common glycerophospholipid. R_1 and R_2 represent two fatty acids, and X may be ethanolamine, choline, serine, inositol, glycerol, or phosphatidylglycerol.

A common name for phosphatidylcholine is lecithin. The proportion of the different glycerophospholipids varies between species of plant and animals and between morphological locations within plants and animals. Glycerophospholipids are the major lipid components of cellular membranes; thus, in animals, the concentration of glycerophospholipids is greatest in muscles and least in adipose tissue. Therefore, as the deposition of intramuscular or marbling fat increases, the contribution of fatty acids from glycerophospholipids to total fatty acids or lipid decreases. In addition, the fatty acid composition of glycerophospholipids varies among animal and plant species. Glycerophospholipids, which usually contain a higher proportion of unsaturated fatty acids than do triacylglycerols in the same animal, usually contain a saturated C_{16} or C_{18} fatty acid at the C-1 position of the glycerol and an unsaturated C_{16} to C_{20} fatty acid in the C-2 position. Names of fatty acid constituents of glycerophospholipids provide the complete identity of the lipids. For example, the phosphatidylcholine that contains stearic and oleic acids would be named 1-stearyl-2-oleoyl-3-phosphatidylcholine.

Plasmalogens are a type of glycerophospholipid in which the C-1 substituent on the glycerol moiety is bonded by an α, β-unsaturated ether linkage in the cis configurations rather than by an ester linkage. Ethanolamine, choline, and serine are the principal constituents esterified to the phosphate group.

Sphingophospholipids, which are more commonly called sphingomyelins, are found in relatively large quantities in brain and nervous tissue. Sphingomyelins consist of a long-chain fatty acid, phosphoric acid, choline, and a complex amino alcohol called sphingosine (Figure 3.4). Choline and ethanolamine are the most common amino alcohols esterified to the phosphoric acid.

A higher proportion of polyunsaturated fatty acids incorporated in phospholipids as opposed to triacylglycerols reflects the functional differences of these lipids. Triacylglycerols are the storage form of lipids in the adipose tissue of animals and in seeds of plants, whereas the phospholipids, which are structural components of cell membranes, must maintain a fluid nature to permit passage of molecules through them.

The degree of unsaturation of the fatty acids in phospholipids of poikilotherms, such as fish, is related inversely to the water temperature of their environment. These changes are brought about by differences in activities of the elongation and desaturation enzymes. These two activities adapt to environmental

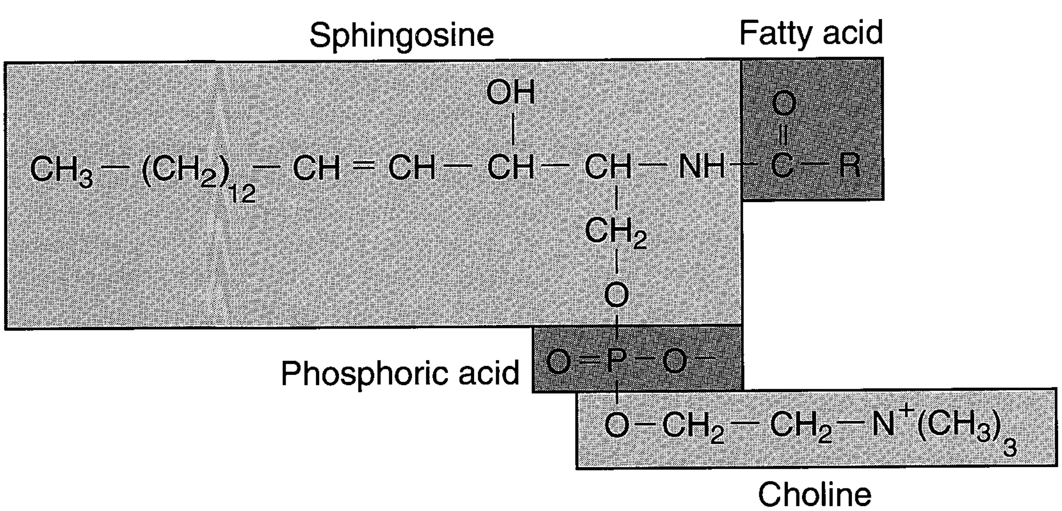


Figure 3.4. Generalized structure of a sphingophospholipid (sphingomyelin).

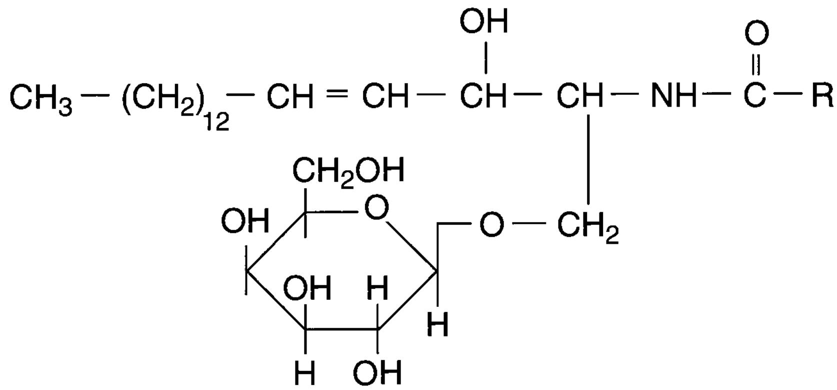


Figure 3.5. Structure of a galactosylceramide. R represents the carbon chain of a fatty acid.

changes such that enrichment of phospholipids with ω-3 polyunsaturated fatty acids in fish from cold water maintains appropriate membrane fluidity. In contrast, the proportion of different fatty acids incorporated into triacylglycerols is affected minimally by water temperature.

Glycolipids

Glycolipids or glycosphingolipids, which are lipids having covalently linked carbohydrates, are distributed widely in every tissue of the animal body; greatest concentration is present in nervous tissue. They occur particularly in the outer leaflet of the plasma membrane and contribute to the cell surface carbohydrate. Most glycolipids are sphingoglycolipids and contain a ceramide (sphingosine + fatty acid) and one or more sugar residues. One of the simplest is galactosylceramide, which is illustrated in Figure 3.5. The sugar residues may be sulfated, which then gives rise to sulfolipids. Additional sugar residues added to a glycosylceramide forms gangliosides.

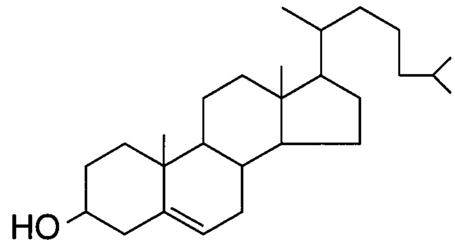
Waxes

Waxes are esters of long-chain saturated and unsaturated fatty acids with long-chain alcohols. The fatty acids in waxes range from 14 to 36 carbon atoms, whereas the alcohols range from 16 to 22 carbon atoms. Waxes are found in large amounts in marine plankton, which is consumed by some marine species of fish. Consequently, in herring salmon, orange roughy, some whales, and other marine species, much of their lipid is in the form of waxes. Terrestrial plants also contain traces of waxes in their foliage, but essentially no waxes are associated with lipids in nonfish meat.

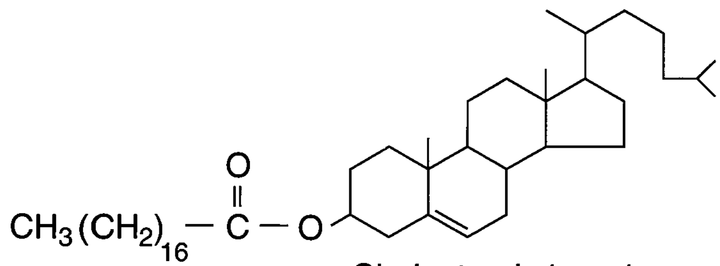
Cholesterol

Cholesterol is a steroid alcohol that is composed of four fused rings as shown in Figure 3.6. Cholesterol is the sterol specific to animal tissues. Cholesterol is present in only trace amounts in plant tissues and functions as an intermediate for synthesis of other sterols such as stigmasterol and β-sitosterol, which are absorbed poorly by the human. Cholesterol and its esters (e.g., cholesteryl stearate, Figure 3.6) with long-chain fatty acids are important components of cell membranes in the animal body, and they perform many vital functions, such as serving as a precursor for the synthesis of bile acids and steroid hormones. The polar hydroxyl group of cholesterol gives the molecule a slightly hydrophilic effect, and the hydrophobic fused ring system provides rigidity that other membrane lipids do not have. Cholesterol thus is an important determinant of membrane fluidity. Because cholesterol has these important functions, the body synthesizes cholesterol daily in proportion to dietary intake so as to maintain appropriate concentrations. Essentially all of the cholesterol in meat is associated with the cell membranes; that in adipose tissue is also in the fat droplets of the fat cells. Because red muscles have more mitochondria, hence more membranes, than do white muscles, the cholesterol content of red muscles is slightly greater than that of white muscles. This is readily evident when comparing the cholesterol content of dark and light meat of poultry.

Most of the cholesterol in animal cell membranes is present as unesterified or free cholesterol, and about 70% of the cholesterol in lipoproteins in blood plasma is present as cholesteryl esters. Thus, most cholesterol in meat and milk and separated animal fats, such as beef tallow and lard, is free cholesterol, whereas most cholesterol in eggs is present as cholesteryl esters.



Cholesterol



Cholesteryl stearate

Figure 3.6. Structure of cholesterol and cholesteryl esters.

4 Federal Programs and Policies Relative to Dietary Fat Issues

Summary

Federal programs and policies are extensive and often involve complex interactions. The overwhelming message from the public and Congress is to "speak with one voice" because communication on nutrition issues is complex by its very nature. Food producers, commodity, and final products are much influenced by federal activities. When federal policies and consumer interests coincide, the food industry can be very responsive.

Introduction

This chapter provides an overview of the many federal programs and policies relative to dietary fats. Because the federal effort is so extensive, only general coverage can be given and some incompleteness may result from attempting to condense information. The reader is advised to consult the appropriate programs where precise data are necessary.

Major Federal Efforts

Interagency Committees

In response to Congressional desire for the government to "speak with one voice," the various federal agencies frequently work together in interagency committees. Most coordinate activities and involve primarily the U.S. Department of Agriculture (USDA) and the Department of Health and Human Services (DHHS), but several other agencies also have important roles to play.

Interagency Committee on Human Nutrition Research

Since 1983, nutrition research at the federal level has been coordinated through the Interagency Committee on Human Nutrition Research (ICHNR), cochaired by the Assistant Secretary for Science and Education (USDA) and the Assistant Secretary for Health (DHHS). Representatives from the Office of Science and Technology Policy (OSTP), Department of Commerce (DOC), Department of Defense (DOD), Agency for International Development (AID), Veterans Administration (VA), National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF) also serve on the ICHNR. The Division of Nutrition Research Coordination (DNRC) of the National Institutes of Health (NIH) has served as Executive Secretariat to the ICHNR since 1986 (Danford, 1990a).

Human Nutrition Research Information Management System

One mechanism for information exchange and coordination used by various federal agencies has been the Human Nutrition Research Information Management (HNRIM) system. Established in 1982 and housed in the DNRC office, the HNRIM system is a computerized database and data retrieval system containing information on nutrition research programs of the DHHS, USDA, VA, AID, DOD, DOC-NOAA, NASA, and NSF. The HNRIM resulted in part from a congressional mandate delivered to the Secretaries of Agriculture and Health and Human Services. It was developed under the guidelines of a joint task force and is available to the public for purchase through the National Technical Information Service of the Department of Commerce (Danford, 1990b).

National Nutrition Monitoring System

The National Nutrition Monitoring System (NNMS) has its origin in the Food and Agriculture Act of 1977 (Public Law 95-113). The NNMS is a complex assortment of interconnected activities that provides regular data and information from all federal research and survey activities related to food, diet, nutrition, and health but primarily to those with USDA and DHHS. It includes such major components as food supply determinations, food and nutrient consumption measurements, food composition measurements, assessment of dietary knowledge and attitude, and measures of nutritional and health status (Interagency Committee on Nutrition Monitoring, 1989).

The first comprehensive report on the NNMS was prepared in 1986 by a four-member, expert panel. The second report (Life Sciences Research Office, 1989) was prepared by the Life Sciences Research Office (LSRO) of the Federation of American Societies for Experimental Biology (FASEB), under contract to DHHS and USDA. The LSRO panel was asked to conduct a scientific review and assessment of data available through NNMS and other sources on the dietary nutritional status of the U.S. population. The two reports are the basis of joint reports by DHHS and USDA to Congress. This second report also provided an in-depth analysis of two areas of public health concern, namely iron nutriture and the nutritional risk factors for cardiovascular disease (Life Sciences Research Office, 1989).

Dietary Guidelines for Americans

The dietary guidelines for Americans (U.S. Department of Agriculture, U.S. Department of Health and Human Services, 1990) are listed in Figure 4.1.

This current set of guidelines under the title of *Nutrition and Your Health: Dietary Guidelines for Americans* is the 1990 revision of the 1985 guidelines. Beginning in 1988, a Federal Advisory Committee of nine nutrition scientists appointed by the USDA and DHHS reviewed the 1985 guidelines and provided suggestions for revision. The committee members used the report described in the next section (U.S. Department of Health and Human Services, 1988) and the National Research Council's report on diet and health (National Research Council, 1989) as the basis for their deliberations. The dietary guidelines for Americans are particularly important as they are used for educational efforts by federal programs and private agencies. In addition, there are policy implications to the guidelines, because they can be used to judge other federal efforts, such as the school lunch programs and several nutrition monitoring and education programs that are mandated to be in accord with currently approved guidelines.

Of the current guidelines, perhaps two have major relationship to food fats and health. The first dietary guideline is "eat a variety of foods." Another is entitled, "choose a diet low in fat, saturated fat, and cholesterol." More indirectly related are guidelines stating "maintain healthy weight" and "choose a diet with plenty of vegetables, fruits, and grain products" (Figures 4.2 and 4.3). As recommended by the committee, the guidelines in the third edition were reworded to be more positive and more specific food selection information was provided to help consumers follow the guidelines.

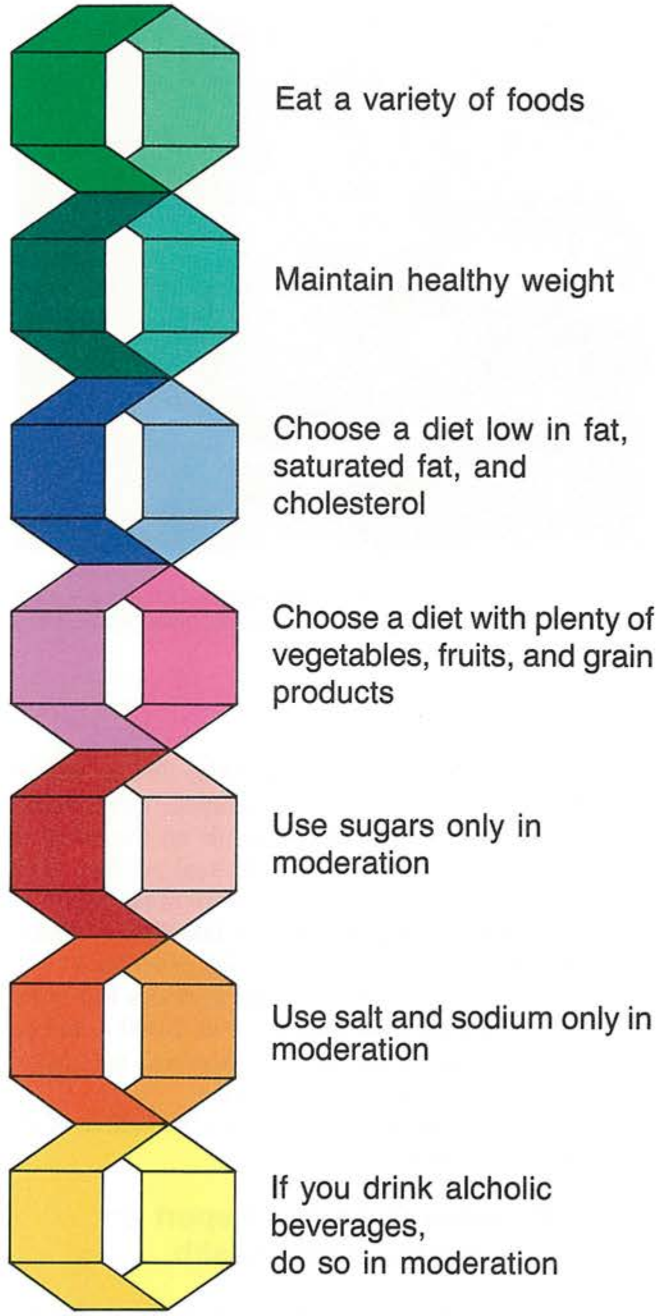
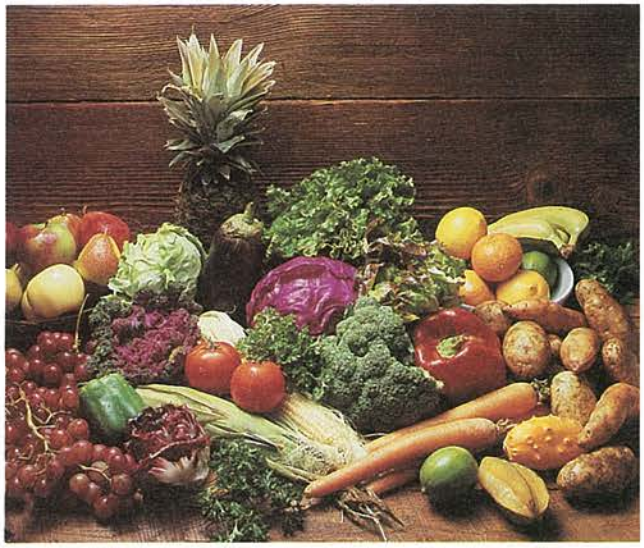
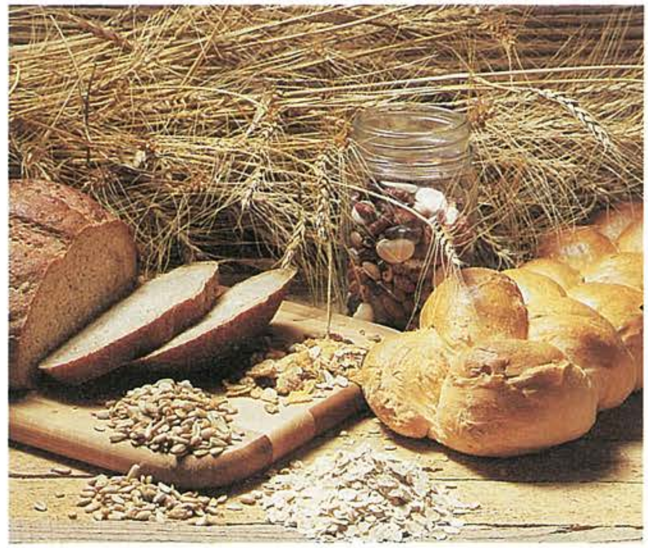


Figure 4.1. Dietary guidelines for Americans (U.S. Department of Agriculture, U.S. Department of Health & Human Services, 1990).

Of relevance to this report, the text accompanying the guideline regarding choosing a diet low in fat suggests the following numerical goals for fat and saturated fat. No numerical goal is suggested for cholesterol.





Figures 4.2 and 4.3. **The cover photograph contains a variety of foods that are low in fat. The foods shown above represent some vegetables, fruits, and grain products that should be included in a healthy diet. Photographs by Peter Krumhardt, Madrid, Iowa.**

1. Total fat. An amount that provides 30% or less of calories is suggested. Thus, the upper limit on the grams of fat in your diet depends on the calories you need. For example, at 2,000 kcal per day, your suggested upper limit is 600 kcal from fat (2,000 × 0.30). This is equal to 67 g of fat (600 ÷ 9, the number of kcal each gram of fat provides.)
2. Saturated fat. An amount that provides less than 10% of calories (less than 22 g at 2,000 kcal per day) is suggested. All fats contain both saturated and unsaturated fat (fatty acids.)
3. Cholesterol. Animal products are the source of all dietary cholesterol.

Surgeon General's Report on Nutrition and Health

This report (U.S. Department of Health and Human Services, 1988) was issued as a follow up report to the 1979 publication of *Healthy People: The Surgeon General's Report of Health Promotion and Disease Prevention*, which pointed toward environmental and behavioral changes Americans might make to decrease losses from morbidity and mortality. Nutrition was one such focus for change.

That earlier report was followed by a 1980 report, *Promoting Health Preventing Disease Objectives for the Nation*, that had 17 specific quantifiable objectives in nutrition designed to decrease risks and to prevent illness and death. The same year, the first edition of the dietary guidelines from the USDA and DHHS was published.

Relationship to Other Reports

Shortly following the Surgeon General's report, the Committee on Diet and Health of the Food and Nutrition Board of the National Research Council (NRC) issued a report entitled *Diet and Health: Implications for Reducing Chronic Disease Risk* (National Research Council, 1989). Both reports provide high visibility to the issue of food fats and health. The NRC report recommended that all individuals should decrease their fat intake to 30% or less of total calories and was expected to lead to a population mean intake substantially below 30% of calories. In addition, saturated fatty acids were to be 10% or less of calories, and the intake of cholesterol was recommended to be less than 300 mg per day. Finally, polyunsaturated fatty acid (PUFA) intake of individuals was limited to 10% of total calories, even though PUFAs decrease serum cholesterol. This recommendation is based on reports of negative side effects of too high a proportion of PUFAs. This change in recommendation is different from prior recommendations that encouraged greater PUFA intake. The NRC report also distinguished between omega-6 polyunsaturated fatty acids and omega-3 polyunsaturated fatty acids; the latter are most frequently obtained from fish products. The major justification for limitation of fat in the diet, especially for saturated fatty acids, would relate to an expectation of lower coronary heart disease incidence. The NRC report indicated that the picture is less clear for the risk of cancer and other chronic diseases. The NRC committee concluded that the recommendations for decreasing incidence of heart disease would not be detrimental to incidence of other diseases. Other reports have posed certain arguments against mass intervention, recommending programs for high-risk individuals instead (American Council on Science and Health, 1988).

Nutrition Research Programs

All of the agencies participating in the ICHNR have some human nutrition research activity. The total NIH budget for biomedical research was almost $7 billion in fiscal year 1989, of which about $287 million (4%) went to human nutrition research (Danford, 1990a). This amount represents, by far, the largest federal contribution to human nutrition research. Many scientists, however, think the amount is small relative to the importance of nutrition to human health maintenance. Nutrition research supported by NIH includes studies on the effects of nutrients on human growth and development, health maintenance promotion, disease prevention, and disease treatment. The primary nutrition mission of NIH lies in biomedical and behavioral research and training. However, NIH also funds nutrition education for professionals and the public as an integral part of many research programs.

Each of the 12 institutes of the NIH supports nutrition research as it relates to their particular research mission. Three institutes each have budgets on an order of magnitude similar to that of the entire USDA human nutrition research budget. These are the National Cancer Institute (NCI), National Heart, Lung, and Blood Institute (NHLBI), and National Institute of Diabetes, Digestive, and Kidney Diseases (NIDDK) (Danford, 1990a). The NCI and NHLBI support studies of the role of different nutrients as well as dietary habits on the etiology, prevention, or the treatment of cancer and coronary heart disease. The NIDDK supports studies related to the requirement, bioavailability, and metabolism of nutrients and other dietary components at the organ, cellular, and subcellular levels. The biomedical and behavioral aspects of obesity and other eating disorders also receive special interest. The National Institutes for Child Health and Development and the National Institute for Aging focus on nutrition for children and the elderly. By far the largest portion ($269 million) of NIH nutrition research was through the extramural program supporting universities and other research centers.

Nutrition research within USDA was about $62 million in different research units during fiscal year 1989 (U.S. Department of Agriculture, 1989). The Agricultural Research Service (ARS) spends the largest portion of USDA human nutrition dollars in their intramural human nutrition research located primarily at five different research centers. The Cooperative State Research Service (CSRS) supports human nutrition research at universities through so-called "formula funds" that go to the various Agriculture Experiment Stations and other institutions, as well as through competitive grants. The Competitive Research Grants Office (CRGO) of CSRS administered the Competitive Grants Program; these funds are available to all universities, including those beyond the land grant university system. The Competitive Grants Program was initiated with an initial goal of $5 million for human nutrition research, but in more recent years human nutrition research has been funded to the extent of 1 to $3 million annually. These limited funds have been focused primarily on human nutrient requirements. The National Research Initiative has led to an increase to $5 million for fiscal year 1991 and a proposed administration budget for fiscal year 1992 of $13 million.

Nutrition Education and Information

The fiscal year 1989 USDA budget was about $149 million for education and information efforts relative to human nutrition. Constant attention is given to the goal for the federal government to "speak with one voice" when issuing dietary guidance. The joint DHHS and USDA effort on dietary guidelines is important in that regard. A major focus of such activities is to improve linkages between research and information activities intended to cover broad audiences in a factual and helpful manner.

National Cholesterol Education Program

The National Cholesterol Education Program (NCEP) is intended to provide a more specific set of recommendations to basic policies developed by an NIH Consensus Development Conference on lowering blood cholesterol to prevent heart disease (Ernst and Cleeman, 1988; Ernst et al., 1988). Dietary therapy to lower low-density lipoproteins (LDL)-cholesterol concentrations in blood is the primary goal of the NCEP.

The Step-One Diet of the NCEP calls for intake of total fat at less than 30% of total calories, saturated fatty acids at less than 10% of total calories, and cholesterol at less than 300 mg per day. If desired changes are not achieved, the Step-Two Diet is begun.

This diet requires a decrease of saturated fatty acids to less than 7% in calories and cholesterol to less than 200 mg per day. If the Step-Two Diet does not reach the desired goals for total and LDL-cholesterol, then drug therapy is recommended. A variety of drugs is suggested, including bile acid sequestrants, nicotinic acid, and cholesterol synthesis inhibitors. These drugs are judged to be effective in lowering LDL-cholesterol concentrations, but their effect on coronary heart disease incidence and their long-term safety have not yet been established.

Some recent scientific reports, as well as popular literature, have been critical of some of the recommendations in the NCEP. They contend that the long-term studies that provide much of its basis have not demonstrated a clear-cut relationship of diet to serum cholesterol or an effect on overall mortality. One report estimates increase in life expectancy from 3 days to 12 months (American Council on Science and Health, 1989). Critics challenge the NCEP as a population-based program more than as an individual program for selected persons (American Council on Science and Health, 1988; Harper, 1989).

Potential Current and Future Policy Issues

Food Labeling

Many federal efforts are now focused on food labeling. The Food and Drug Administration (FDA) of DHHS issued a Federal Register notice indicating that a process of revising food labeling policy is underway (U.S. Food and Drug Administration, 1989). The Federal Register notice provided a time for comment on five topics being considered. These were (1) whether to revise the requirements for nutrient labeling, (2) whether to change the nutrition label format on packages, (3) whether to require revised requirements for ingredient labeling, (4) whether to formally define commonly used food descriptions and reconsider the use of standards of identities for foods, and (5) how to reasonably permit the use of messages on food labels that link components to the prevention of disease.

One major issue is that there may be limits to the amount of information that can be useful to the public. For example, if all saturated fatty acids do not contribute equally to serum cholesterol, should the label include specific fatty acids or should the label lump those that increase serum cholesterol and those that do not under some useful description? Should trans fatty acids be on the label? Other issues of concern include: Can the typical consumer translate label information to guidelines, such as 30% of calories from fat, or should labels state only grams of fat per day? Are substitutions permitted within some limits, and should the label broadly define such differing sources?

Federal Research Funding

The primary policy questions relate to amount of funding; that is, is it appropriate for the United States to spend only about 4% of the biomedical budget on human nutrition research related to diagnosis, prevention, and treatment of diseases, or is the role of nutrition so significant as to justify increased amounts? Is it appropriate to spend about five times the dollars on biomedical research on topics related to human nutrition and disease than is spent on nutrition research for the significantly larger "healthy" population? Specifically, what are reasonable amounts for competitive grants within USDA? Where does responsibility lie for alteration of animal and plant sources of fats and oils in relation to the clinical aspects of heart disease or other diseases? When the primary purpose of altering the nature of plant and animal products is for better human health, is that the responsibility of NIH, USDA, or both?

Dietary Messages to the Public

Certain issues become very important as the public is given more messages regarding diet and health. Specific issues include whether the average consumer can calculate the percentage of daily calories from fat based on dietary information or would grams of fat per serving or per unit of food sold be more definitive as a goal? Do we know enough about individual variation to make broad public recommendations? What happens to other causes of death when one focuses on heart disease, and should those recommendations be the overwhelming dietary message? Are dietary guidelines for adults identical with or different from those for children, pregnant women, and the elderly? How does one communicate these facts to the public? Evidence indicates no relationship of serum cholesterol to heart disease in older patients; should this be reflected in the message? Do the dietary messages promote the idea of total daily fat intake so as to allow a person who likes a particular food with higher fat content to compensate for it by substituting another food?

Hunger and Undernutrition

Recent reports suggest that greater than 30% of the infants in this country participate in the federal Special Supplemental Food Program for Women, Infants, and Children (WIC). This program has more than 4 million participants. Do the same public policy issues and dietary recommendations fit those situations where there is hunger and undernutrition? Is the value of fat as a caloric source the same for those individuals who participate in various federal food assistance programs? As the population increases, will there be a time when the added calories from plant and animal fats are considered desirable to meeting energy requirements? Will the changes in agricultural production being suggested for the short-term apply to the long-term and on a global basis, relative to the need for basic sustenance?

Implications for Food Commodity Groups and Food Industry

Major efforts are being made in both plant and animal agriculture to respond to the real and perceived needs of consumers. Trimming of fat from meat animal carcasses has provided immediate decreases in the fat content of an average serving size of meat. Low-fat dairy products have appeared on a wide scale in the last few years. New plant oils are appearing on the market, and their benefits are being touted. One of the important questions is whether changes in animal and plant agriculture can be made rapidly enough to react to new human health information. Does the target change more rapidly than the production, processing, and marketing systems? Are certain changes permanent? Response may depend on the soundness of the scientific data as they are related to public messages. If so, it seems that all involved should place a high priority on being responsible and clear in such messages.

5 Composition of Milk Fat

Summary

Bovine milk, which is the major type of milk consumed in the United States, contains about 50% long-chain saturated fatty acids in the fat portion of the milk. The fat also contains about 30% monounsaturated, 3% polyunsaturated, and 10% short-chain saturated fatty acids. Cholesterol is present in the fat portion of milk, and consumption of milk with a decreased proportion of fat also decreases consumption of cholesterol. Any conventional genetic method used to change milk fat percentages or to change the composition of milk will make only slow progress. The amount and composition of milk fat can be changed by nutrition, but those changes cause undesirable side effects in the cows. Possibly, techniques in biotechnology can be used in the future to change the composition of milk produced by cows.

Introduction

Milk consumption by humans is either by nursing infants or by individuals of every age consuming milk from domesticated animals, which include cows, water buffalo, goats, and sheep. About 92% of worldwide milk consumption from domesticated species is from cows (Jenness, 1974), and the percentage is at least 99% for the United States. Discussion will focus, therefore, on the composition of bovine milk fat, with occasional comparisons with human milk.

Table 5.1. Average composition of bovine and human milk (adapted from Jenness, 1974, pp. 60, 73)

	Milk source	
Ingredient	Bovine (%)	Human (%)
Total solids	12.7	12.4
Fat	3.7	3.8
Protein	3.4	1.0
Lactose	4.8	7.0
Minerals	0.7	0.2

Milk contains water, fat, protein, carbohydrate, and minerals (Table 5.1). Each ingredient, but especially protein and calcium, can make important contributions to human nutrition (Figure 5.1). Dietary energy is provided by fat, carbohydrate (i.e., lactose), and protein. The average available energy is 66 kcal/100 ml for both bovine and human milks, and the calories originating from fat of whole milk are 52% for human milk and 50% for bovine milk. An average 8-ounce glass of 3.5% whole milk from cows would contain 146 kcal, and 49% would be from fat; corresponding figures are 115 kcal and 35% for 2%-fat milk, and 95 kcal and 21% for 1%-fat milk.

Composition of Bovine Milk Fat

Types of Lipid

The classes of lipids in milk are triacylglycerols, diacylglycerols, monoacylglycerols, free fatty acids, phospholipids, sterols, and sterol esters. For bovine milk, 97 to 98% of the lipid is triacylglycerol, about 1% is phospholipids, and all other classes are less than 0.5%. This report will deal with the total fatty acid composition of bovine milk fat, i.e., largely triacylglycerols.

Figure 5.1 **Milk and milk products are important sources of nutrients. Photograph courtesy of U.S. Department of Agriculture.**

Fatty Acid Composition

A typical fatty acid composition of bovine milk fat is listed in Table 5.2 from data presented by Jenness (1974). Other individual reports vary somewhat, but the four primary fatty acids are always myristic, palmitic, stearic, and oleic. The ratio of various fatty acids, however, can be modified by a number of factors.

Saturated Fatty Acids

There are two categories of saturated fatty acids in bovine milk fat. The first category is the short-chain (C_4 to C_{10}) saturated fatty acids (i.e., butyric, caproic, caprylic, and capric). This category generally constitutes about 10% of the weight of total fatty acids in milk fat from ruminants but is very low or absent from milk fat of other species. The molecular percentage obviously is greater because of the lower molecular weights.

The second category, long-chain saturated fatty acids (C_{12} and greater), constitutes slightly over 50% of the total weight of fatty acids. These are the ones criticized most often with respect to potential detrimental effects on human health, especially related to cardiovascular disorders. There is recent evidence, however, that stearic acid is not nearly as conducive to circulatory disorders as had been suspected previously (Bonanome and Grundy, 1988).

Unsaturated Fatty Acids

There also are two categories of unsaturated fatty acids in bovine milk fat. The monounsaturates, primarily palmitoleic and oleic, normally constitute about 30% of the total weight of fatty acids. The two most prevalent polyunsaturated fatty acids are linoleic and linolenic acids, but these two only constitute about 3% of the total weight. Bovine milk fat, or butter, can contribute some essential fatty acids to human nutrition, but normally milk fat is not a major source.

Table 5.2. Fatty acid composition of bovine and human milk (adapted from Jenness, 1974, pp. 10, 11, 12)

Fatty acid	Cow milk (% by weight)	Human milk (% by weight)
Butyric (4:0)	3.3	—
Caproic (6:0)	1.6	trace
Caprylic (8:0)	1.3	trace
Capric (10:0)	3.0	1.3
Lauric (12:0)	3.1	3.1
Myristic (14:0)	9.5	5.1
Palmitic (16:0)	26.3	20.2
Palmitoleic (16:1)	2.3	5.7
Stearic (18:0)	14.6	trace—5.9
Oleic (18:1)	29.8	46.4
Linoleic (18:2)	2.4	13.0
Linolenic (18:3)	0.8	1.4
Total	98.0	102.1

Trans Fatty Acids

There are two major sources of trans fatty acids in the human diet, and, for both sources, $C_{18:1}$ (i.e., elaidic acid) is the major trans fatty acid. First, and primary, are the trans fatty acids that originate from partly hydrogenating vegetable oils for use in human foods. Second, ruminant fats also are a source of trans fatty acids because of hydrogenation during digestion in the rumen. Christie (1981) reported data indicating that part of the 18:1 fatty acids in milk fat have the trans configuration across the double bond. During a winter month, the fatty acid composition was 19.9% cis and 2.5% trans, but during a summer month, the composition changed to 24.3% cis and 6.4% trans. Ohlrogge (1983) indicated that ruminant fats generally have 2 to 8% trans isomers, whereas partly hydrogenated vegetable oil may contain from 5 to 50% trans fatty acids. He also showed data from samples of fat taken from humans, suggesting that patterns of fatty acids indicated the majority of stored trans fatty acids originated from partly hydrogenated vegetable oil.

Many aspects relating to the metabolism and the effects of trans fatty acids have been examined (Applewhite, 1983; Emken, 1983; Gottenbos, 1983; Kritchevsky, 1983; Kummerow, 1983; Ohlrogge, 1983). Trans fatty acids can affect many aspects of fatty acid and lipid metabolism, and there are widely differing opinions as to whether the changes potentially could cause serious effects in the human population. The general consensus, however, seems to be that trans fatty acids, especially elaidic, do not have any effects that are more serious than saturated fatty acids.

Cholesterol

Cholesterol is a normal constituent of milk, and about 80 to 85% of the cholesterol is associated with milk fat, which includes that associated with the fat globule membrane (Jenness, 1974; Patton et al., 1980). Richardson (1968) reported that bovine milk fat contained 360 mg of cholesterol per 100 g of fat, and that 88% of the cholesterol was free and 12% was as cholesterol esters. The total cholesterol in 8 ounces of 3.5% fat whole milk is listed as 34 mg by Pennington and Church (1985), and this agrees well with an average of 35 mg calculated from data of Wood and Bitmann (1986). If low-fat milk with 1 or 2% fat is consumed, then cholesterol per 8-ounce glass equals 10 or 18 mg, respectively (Pennington and Church, 1985). Skim milk contains 4 mg per 8-ounce glass. Thus, it is possible to consume significant quantities of milk, especially low-fat or skim milk, and still maintain daily cholesterol consumption at 300 mg or below.

Flavor and Texture of Milk Fat

Fat is an important factor in the flavor and texture of milk and milk products. One of the greatest deterrents for individuals who are accustomed to drinking whole milk to change to skim milk or 1% fat milk is the extremely watery taste and the absence of any major sensation of texture in the skim milk. Ice creams that are low in fat generally have a less pleasing taste and texture than do products that do not have the fat decreased or removed. The short-chain fatty acids that are present in butter give a distinctive flavor to butter and to foods that contain butter. The saturated fatty acids, however, do cause butter to be firm and difficult to spread at refrigeration temperatures.

Public Perceptions of Milk Composition

The primary positive perceptions of milk compositions are that (1) milk contains high quality protein that is valuable for human nutrition, (2) milk contains high concentrations of readily-available calcium without which it is difficult to achieve recommended dietary intakes of calcium, and (3) milk is a valuable source of vitamins. Negative perceptions are that milk is very high in cholesterol and in saturated fatty acids, both of which can be detrimental to cardiovascular health. There also can be concerns about milk allergies with respect to milk proteins or to lactose intolerance, especially in noncaucasian populations.

Comparisons with Human Milk

There are major differences between the composition of human and bovine milk fats (Table 5.2). Human milk contains approximately half as much saturated fatty acids (35 versus 63%), and almost none of these are the short-chain fatty acids. There is about a 1.6-fold greater amount of monounsaturated fatty acids (52 versus 32%) and over a 4-fold greater amount of polyunsaturated fatty acids (14.4 versus 3.2%), with linoleic acid being the primary one.

Changing Bovine Milk Fat Composition Biologically

Composition of bovine milk can be changed during processing, which will be discussed in another section of this report, or it may be changed biologically as it is synthesized by the cow, which will be discussed in subsequent paragraphs.

Normal Variations of Milk Fat

Genetic and environmental factors that may affect composition of milk have been discussed (Linn, 1988; Touchberry, 1974). Milk composition is affected by both genotype and environment. Environment can include nutrition, management, age of cows, and stage of lactation. Touchberry (1974) presented data about variations for both fat percentage in milk and yield of fat per lactation. He reported data for one large study that indicated the standard deviation (i.e., half of the average of the difference among cows) for fat percentage averaged about 8.9% for Holstein cows, and the value was very similar for other breeds, averaging 8.5% over the five major dairy breeds.

Neither standard deviations nor other statistical parameters are available to any major extent for evaluating variations in ratios of individual fatty acids present in milk fat. Percentage milk fat is the ingredient measured most often and is measured many fold more commonly than is the fatty acid composition of milk fat. There can be major variations, however, in the ratios of milk fatty acids, which are illustrated in Table 5.3. In general, Table 5.3 shows there can be significant changes in the saturated fatty acids, myristic, palmitic, and stearic, and in the polyunsaturated fatty acids, linoleic and linolenic. Feeding diets with a very high ratio of grain to forage causes "milk fat depression," which is a decrease in the total amount of milk fat produced. Davis and Brown (1970) summarized that such a dietary change generally causes the percentages of palmitic and stearic acids to decrease and the percentages of oleic, linoleic, and linolenic acids to increase.

Changing Composition of Milk Produced

Touchberry (1974) discussed that the amount of progress that could be made in genetically changing the composition of milk is limited by the amount of variation for a particular constituent, and he concluded there is minimal opportunity for making major decreases or increases in the amount of fat produced in milk. The opportunities to genetically

Table 5.3. Examples of major changes in the fatty acid composition of bovine milk fat (by weight as a percent of total)

Fatty acid	Control[a] (%)	Protected safflower oil[a] (%)	Silage[b] (%)	Roots[b] (%)
Butyric (4:0)	3.6	1.6	2.8	3.8
Caproic (6:0)	3.3	2.2	2.0	2.6
Caprylic (8:0)	1.3	0.9	0.7	0.7
Capric (10:0)	2.5	2.4	1.7	3.2
Lauric (12:0)	2.9	2.7	2.2	2.6
Myristic (14:0)	10.4	8.3	5.4	8.0
Palmitic (16:0)	30.4	15.6	29.7	41.3
Palmitoleic (16:1)	1.9	1.1	—	—
Stearic (18:0)	12.1	11.5	10.5	6.1
Oleic (18:1)	24.2	24.2	33.4	19.6
Linoleic (18:2)	2.6	24.6	0.9	1.0
Linolenic (18:3)	1.7	2.4	0.6	0.9

[a]Christie, 1981, p. 218.
[b]Hilditch and Williams, 1964, p. 148. (The silage was grass silage and the roots were turnips. The cows were stall-fed beef cows and also were fed oat straw *ad libitum*.)

change ratios of individual fatty acids seems even less.

Linn (1988) summarized several factors that might alter fat yield or composition. He acknowledged the differences in percentage of fat in milk produced by different breeds but also concluded that the percentage of fat could only be changed slowly. With respect to environmental or managemental factors, he observed only a slight decrease in fat percentage over the first five lactations. During the first half of a lactation, the proportion of long-chain fatty acids decreases slightly, but no further changes occur thereafter. During summers, milk averages 0.4% less fat than during winter, and the fat is lower in palmitic acid relative to stearic, linoleic, and linolenic acids.

Nutrition seems to be the best alternative for altering the amount or composition of milk fat (Linn, 1988). For example, when a high ratio of grain to forage is fed, the amount of fat produced can decrease as much as 60% and the C_{18} monounsaturated and polyunsaturated fatty acids increase, whereas the C_{16} and C_{18} saturated fatty acids decrease. There is one major problem, however, in that cows fed high grain and low forage diets can become grossly obese and often do not continue a productive life. Adding fats directly to diets can alter milk composition somewhat, but to be very successful the fats must be protected so that they will bypass the rumen without affecting rumen fermentation or being hydrogenated if they are unsaturated. Production of a high ratio of acetate to propionate in the rumen will maintain a high rate of milk fat production, but the ratio will have little or no effect on fat content of milk if the ratio is above about 2.2. Enough propionate to decrease the acetate to propionate ratio below 2 will cause a proportional decrease in milk fat percentage.

Other nutritional factors that may affect milk fat percentage or composition include type of dietary carbohydrate, how ingredients are processed (i.e., pelleting or grinding finely), forage particle size, and type of buffers fed (Linn, 1988).

Potential Methods of the Future

There do not seem to be practical methods now available to effectively cause major changes in the composition of milk, but such methods will need to be pursued vigorously in the future. Currently, bovine somatotropin (BST) is the focus of attention, because it increases total milk production without causing significant changes in composition. In the future, it may be possible to feed cows to cause "milk fat depression," whereby the amount of milk fat is decreased and the composition is changed to decrease saturated fatty acids, and concurrently use BST to produce more milk and decrease body fat deposition.

Furthermore, we are in the era of molecular biology, and it may be possible to create transgenic cows that will have an altered expression of genes for fat synthesis to decrease the amount of fat or create a fatty acid composition that is highly desired by a majority of consumers. Conversely, expression of genes for synthesis of protein may be promoted highly to produce milk that is higher in protein content because protein is the most important dietary constituent of milk.

6 Composition of Fat in Red Meat Animals and Fish

Summary

Triacylglycerols are the predominant form of fat in red meat and fish, but minor amounts of phospholipids, cholesterol, waxes, and fat-soluble vitamins are also present. The triacylglycerols are deposited as fat within the muscles of meat, between the muscles, and around the outside of meat cuts. The latter two deposits of fat can be removed while cutting meat for retail display, before cooking, or on the plate while eating. Except for a small amount leached during cooking, the fat within muscles cannot be removed and is consumed along with the muscles. Phospholipids are present in the membranes of cells and consequently they also are consumed.

Because triacylglycerols and phospholipids are consumed when eating meat and both are comprised primarily of fatty acids, the fatty acid composition of selected retail cuts of beef, pork, veal, lamb, variety meats, sausage, as well as lean and fatty fish and shellfish, is presented in tables of this chapter. Also included in these tables are the fat, total kcal, and cholesterol content of a 100 g cooked serving of each meat item. The tables also provide the percentage of total fat that is present as saturated fat, monounsaturated fat, and polyunsaturated fat for each item. From these data, it is evident that a number of retail cuts from red meat species provide less than 30% of total calories from fat.

The effects of species, age, gender, breed, body type, nutrition, and management of meat-producing animals as well as meat cookery on fat and cholesterol content and fatty acid profile are described for the red meat species. The factors affecting fat and cholesterol content and fatty acid profile of fish also are discussed.

Introduction

Fat is found in nearly every anatomical location in the animal body. In cattle, pigs, and sheep, however, fat accumulates in several major sites or depots, namely under the skin (subcutaneous fat), between muscles (intermuscular fat), within muscles (intramuscular fat, also called marbling), around the kidney (kidney fat), on the inner walls of the thoracic, abdominal, and pelvic cavities, and along and around the stomach and intestines (mesenteric fat) (Allen et al., 1976). Most of these fat deposits can be, and usually are, trimmed from meat during fabrication into retail cuts. Little of the fat between muscles and none of the marbling fat, however, can be trimmed from retail cuts during conventional fabrication. Only by muscle boning (separation of individual muscles or muscle groups) can fat between muscles be removed. Very little muscle boning is performed in conventional retail cut fabrication. The amount of subcutaneous fat left on the surface of retail cuts of meat varies from none to one-half inch, but most retailers are trimming them closer than ever before. Nearly all subcutaneous fat left on the surface of meat cuts, as purchased, can be trimmed either before cooking or, along with the fat between muscles, subcutaneous fat can be cut away on the plate during eating and does not have to be consumed (Figure 6.1). The fat within muscles, i.e., marbling, however, cannot be removed. It constitutes the major fat deposit on or in meat that is consumed.

In the popular finfish consumed in the United States, most of the lipid is present in the muscles, and the lipid primarily is associated with the phospholipids of muscle cell membranes (Kinsella, 1988). These are low-fat fish, and they generally have 1 to 2% fat in the

Figure 6.1. A variety of lean, well-trimmed meat is available to the U.S. consumer. Photograph by Peter Krumhardt, Madrid, Iowa.

edible portion. Few of the popular finfish have more than 2 to 3% fat, but several species have 10% or more. As fat content increases, however, a greater proportion is deposited as intramuscular lipid that is comparable with marbling in the red meats. In high-fat fish, much of the fat is deposited subcutaneously, but this depot often penetrates into the muscles, increasing intramuscular fat content (Ackman, 1980). The subcutaneous depot predominates along the lateral line and around the belly of fish. Thus, muscle is a major site of lipid deposition in many fish and, hence, the source of much of the lipid associated with eating fish. While not specifically identified as marbling, the lipid present in the muscle of fish varies greatly between species. Finfish are classified as lean or fatty based on their muscle lipid content. This classification of some common species is shown in Table 6.1. In contrast to finfish (Table 6.2), shellfish have a very low

Table 6.1. Species of fish generally classified as lean and fatty (Mutkoski and Schurer, 1981)

Lean			
Bass, channel	Flounder	Muskie	Sheepshead
Blackfish	Fluke	Perch	Skate
Bluegill	Haddock	Pickerel	Sucker
Catfish	Hake	Pike	Sunfish
Cod	Lemon sole	Pollock	Weakfish
Drumfish	Marlin	Scrod	Whiting
Fatty			
Barracuda	Grayling	Mullet	Smelt
Bass, striped	Grouper	Pompano	Snappers
Bluefish	Grunt	Porgies	Sturgeon
Bonito	Halibut	Salmon	Swordfish
Carp	Herring	Sardines	Tuna
Croaker	Kingfish	Shad	Whale
Eel	Mackerel	Shark	Whitefish

Table 6.2. Lipid composition of some finfish (100 g portion) (National Live Stock and Meat Board, 1988)

	Lean finfish				Fatty finfish			
	Cod, Atlantic (dry heat)	Haddock (dry heat)	Flounder (dry heat)	Perch (dry heat)	Tuna light (canned in water)	Salmon, Pink (canned)	Halibut, Atlantic and Pacific (dry heat)	Trout, Rainbow (dry heat)
Total fat (g)	0.86	0.93	1.54	0.70	0.50	6.05	2.94	4.31
Cholesterol (mg)	55.00	74.00	68.00	54.00	35.00	65.00	41.00	73.00
Energy (kcal)	105.00	112.00	116.00	91.00	130.00	139.00	140.00	152.00
Fatty acids								
Saturated, total (g)	0.17	0.17	0.36	0.16	0.16	1.54	0.42	0.84
C_{14}	0.01	0.01	0.06	0.01	0.02	0.05	0.07	0.08
C_{16}	0.12	0.11	0.22	0.11	0.12	1.35	0.27	0.49
C_{18}	0.04	0.04	0.06	0.04	0.02	0.14	0.06	0.16
Other SFA[a]	—	—	0.02	—	—	—	—	0.08
Monounsaturated, total (g)	0.12	0.15	0.30	0.11	0.14	1.81	0.97	1.33
$C_{16:1}$	0.02	0.02	0.07	0.03	0.02	0.47	0.21	0.20
$C_{18:1}$	0.08	0.09	0.15	0.07	0.07	1.07	0.46	0.79
Other MUFA[b]	0.02	0.03	0.08	0.01	0.05	0.27	0.29	0.34
Polyunsaturated, total (g)	0.29	0.31	0.58	0.39	0.13	2.05	0.94	1.54
$C_{18:2}$	0.01	0.01	0.01	0.01	—	0.06	0.04	0.32
$C_{18:3}$	—	—	0.01	0.01	—	0.06	0.08	0.15
$C_{20:4}$	0.03	0.03	0.05	0.08	—	0.08	0.18	0.14
$C_{20:5}$	—	0.08	0.25	0.06	0.05	0.85	0.09	0.18
$C_{22:6}$	0.15	0.16	0.26	0.19	0.07	0.81	0.37	0.55
Other PUFA[c]	0.09	0.03	—	0.04	0.01	0.19	0.17	0.20
Fatty acids as % of total fat								
Saturated	22.37	18.28	23.53	22.86	32.00	25.45	14.28	19.49
Monounsaturated	13.95	16.13	19.61	15.71	28.00	29.92	32.99	30.86
Polyunsaturated	13.72	33.33	37.91	55.71	26.00	33.88	31.97	35.73

[a]SFA = Saturated fatty acids.
[b]MUFA = Monunsaturated fatty acids.
[c]PUFA = Polyunsaturated fatty acids.

lipid content (Table 6.3). The sites, other than intramuscular and subcutaneous, of lipid deposition in fish generally are not consumed. Some species of fish deposit high amounts of lipid in their liver, whereas others have lipid deposits in the mesentery along their intestinal tracts.

The amount of marbling, as well as all fat deposits, vary with animal age and carcass grade in the red meat animal species. Older animals generally have more fat than do younger ones. Additionally, U.S. Prime grade beef, lamb, and veal carcasses have more marbling than U.S. Choice grade carcasses, which, in turn, have more marbling than do the U.S. Select/Good grade carcasses. This is so because degree of marbling, or alternate assessments of it, is the major factor in the determination of the commercial grades of beef, lamb, and veal carcasses. Marbling is not a factor in grading pork carcasses. Total carcass fat, however, increases as grades increase from No. 1 to No. 4, but marbling differs little between grades. The fat, calorie, and cholesterol content of the cooked lean portion of beef and pork by carcass grade are presented in Table 6.4.

Factors Affecting Fat Deposition, Cholesterol Content, and Fatty Acid Profile of Red Meats

Fat deposition and, to some degree, fatty acid profile in meat animals are determined by genetic factors that can be modulated somewhat by dietary and other management practices. Fat deposition also increases with increasing age of the animal and varies somewhat with season. Genetic factors include species of animal, gender, breed, and body type.

Table 6.3. Lipid composition of some shellfish (100 g portion) (National Live Stock and Meat Board, 1988)

				Crab		
	Shrimp (mixed species (moist heat)	Lobster, Northern (moist heat)	Clams (mixed species) canned drained solids	Alaskan, King (moist heat)	Blue (canned)	Blue (moist heat)
Total fat (g)	1.08	0.59	1.94	1.54	1.22	1.78
Cholesterol (mg)	195.00	72.00	67.00	53.00	89.00	100.00
Energy (kcal)	99.00	98.00	148.00	96.00	99.00	102.00
Fatty acids						
Saturated, total (g)	0.29	0.10	0.19	0.13	0.25	0.22
C_{14}	0.01	0.01	0.02	0.01	—	0.02
C_{16}	0.14	0.08	0.12	0.08	0.16	0.14
C_{18}	0.09	0.02	0.04	0.02	0.09	0.06
Other SFA[a]	0.05	—	0.01	0.01	—	—
Monounsaturated, total (g)	0.20	0.16	0.18	0.19	0.22	0.28
$C_{16:1}$	0.06	0.04	0.05	0.05	0.07	0.09
$C_{18:1}$	0.12	0.09	0.07	0.09	0.12	0.15
Other MUFA[b]	0.02	0.04	0.06	0.05	0.04	0.04
Polyunsaturated, total (g)	0.44	0.09	0.55	0.54	0.44	0.68
$C_{18:2}$	0.02	—	0.04	0.02	0.01	0.02
$C_{18:3}$	0.01	—	0.01	0.01	—	0.02
$C_{20:4}$	0.07	—	0.08	0.05	0.06	0.08
$C_{20:5}$	0.18	0.06	0.14	0.29	0.19	0.25
$C_{22:6}$	0.14	0.04	0.14	0.12	0.18	0.24
Other PUFA[c]	0.01	—	0.14	0.05	—	0.07
Fatty acids as % of total fat						
Saturated	26.85	16.95	9.79	8.44	20.49	12.36
Monounsaturated	18.52	27.12	9.28	12.34	18.03	15.73
Polyunsaturated	40.74	15.25	28.35	35.06	36.06	38.20

[a]SFA = saturated fatty acids.
[b]MUFA = monounsaturated fatty acids.
[c]PUFA = polyunsaturated fatty acids.

Table 6.4. Fat, calorie, and cholesterol contents of cooked beef and pork by grade (Buege et al., 1991; National Live Stock and Meat Board, 1988, 1990, 1991)

Species and grade	Fat (g)	Energy (kcal)	Cholesterol (mg)
Beef[a]			
Prime	13.08	245	86
Choice	10.25	219	86
Select/Good	8.86	207	86
Average of all grades[b]	9.91	216	86
Pork[a]			
No. 1	9.34	209	80
No. 2	9.26	207	80
No. 3	9.53	211	80
No. 4	8.52	198	80
Average of all grades[c]	9.32	208	80

[a]One hundred gram portion, lean only.
[b]Weighted average based on distribution of beef among grades, i.e., 6.0% Prime, 66.7% Choice, and 27.3% Select/Good.
[c]Weighted average based on distribution of pork among grades, i.e., 71.7% No. 1, 24.2% No. 2, 3.7% No. 3, and 0.3% No. 4.

Age Effects

Whereas deposition of fat increases with increasing age of the animal, the individual depots differ in the time of onset of lipid accumulation during growth and development (Boggs and Merkel, 1990). Intramuscular fat, which is the major lipid deposit consumed, is a later developing fat depot. In young animals, such as veal, the intramuscular lipid is composed primarily of the phospholipids associated with the membranes present in muscle tissue. Deposition of intramuscular triacylglycerol, i.e., marbling, generally begins after the onset of fat deposition in the other depots of the animal body. Thus, the intramuscular depot has the lowest fat content of all the lipid deposits associated with meat, and calories from fat can be limited to intramuscular lipid if all other fat is trimmed away.

The fat content of meat animals tends to be slightly greater during the winter months than in summer (Allen et al., 1976). Additionally, the fatty acid profile has been reported to be more highly related to season of the year than to animal age, with the saturated fatty acids being lower in winter and highest in summer (Link et al., 1970).

Species Effects

Intramuscular fat represents 15% of total fat in beef carcasses and 10 and 9% in pork and lamb carcasses, respectively (Boggs and Merkel, 1990). Total fat and cholesterol content, as well as the fatty acid profile, in the lean only portion of a composite of all retail cuts of all grades of beef, pork, lamb, veal, and some sausage products is presented in Tables 6.5, 6.6, and 6.7. A 100-g portion of cooked beef, pork, lamb, and veal contains 9.91, 9.32, 9.52, and 6.58 g of fat, respectively. In beef, marbling is the major factor in the determination of quality grade. Obviously then, intramuscular fat content of beef varies with quality grade, i.e., U.S. Prime beef has more intramuscular fat than does U.S. Choice, which, in turn, has more than does U.S. Select grade beef (Table 6.4). The intramuscular fat content of lamb and veal generally does not follow this pattern across grades, even though total carcass fat does. In pork, total fat is lowest in U.S. No. 1 grade carcasses and increases progressively with grade from No. 1 to No. 4, but, like veal and lamb, intramuscular fat content varies only slightly among grades (Boggs and Merkel, 1990).

The fatty acid profile varies widely among species of meat animals. Beef has the highest percentage of saturated fatty acids (~38%) and the lowest percentage of polyunsaturated fatty acids (~3.5% of total). Pork and lamb have similar percentages of saturated fatty acids (30 to 35%), but pork has more polyunsaturated fatty acids (4 to 15%) than does lamb (6.5%). The fatty acid profile of the processed pork products (e.g., ham and bacon) is similar to that of fresh pork. Bacon, however, has considerably more fat than does processed ham and the fresh retail cuts of pork. Of the red meat species, veal has the lowest percentage of saturated fatty acids (28%), but the proportion of polyunsaturated fatty acids (9%) is intermediate to those for beef and lamb, which are on the low end, and pork, which is highest. The percentage of saturated fatty acids of the variety meats of beef and pork, i.e., liver, tongue, and heart, are similar to those of the retail cuts of the species, but they have more polyunsaturated fatty acids (Table 6.8). Sausage products containing beef and pork have fatty acid profiles proportional to the relative content of each species (Table 6.7). Fish have the lowest percentage of saturated fatty acids (10 to 25%) and the highest percentage of polyunsaturated fatty acids (15 to 56%) of all species.

Gender Effects

Males of all meat animal species have less fat than do females at the same age or body weight (Boggs and Merkel, 1990). Castrated male pigs have more fat than either gonadally intact males or females. In cattle and sheep, gonadally intact females are fatter than castrated or intact males. Castration of males is a common practice in the production of livestock species for meat to increase docility.

Table 6.5. Lipid composition of composite of beef cuts and ground beef (100 g portion) (National Live Stock and Meat Board, 1990)

	Beef composite of all cuts (lean-only, cooked)	Ground beef (pan fried)			
		85% lean		73% lean	
		Medium	Well done	Medium	Well done
Total fat (g)	9.91	14.44	14.03	22.96	19.26
Cholesterol (mg)	86.00	81.00	93.00	89.00	98.00
Energy (kcal)	216.00	239.00	249.00	308.00	288.00
Fatty acids					
Saturated, total (g)	3.79	5.67	5.52	9.02	7.56
C_{10}	0.01	0.02	0.02	0.02	0.02
C_{12}	0.01	0.02	0.02	0.02	0.02
C_{14}	0.28	0.41	0.40	0.65	0.55
C_{16}	2.25	3.27	3.18	5.19	4.36
C_{18}	1.22	1.71	1.65	2.71	2.27
Monounsaturated, total (g)	4.17	6.32	6.14	10.05	8.43
$C_{16:1}$	0.35	0.54	0.53	0.86	0.72
$C_{18:1}$	3.80	5.52	5.37	8.78	7.37
$C_{20:1}$	0.01	0.01	0.01	0.02	0.01
Polyunsaturated, total (g)	0.34	0.54	0.53	0.85	0.72
$C_{18:2}$	0.27	0.40	0.39	0.63	0.53
$C_{18:3}$	0.03	0.06	0.06	0.09	0.08
$C_{20:4}$	0.04	0.06	0.05	0.09	0.08
Fatty acids as % of total fat					
Saturated	38.24	39.27	39.34	39.29	39.25
Monounsaturated	42.08	43.77	43.76	43.77	43.77
Polyunsaturated	3.43	3.74	3.78	3.70	3.74

Table 6.6. Lipid composition of composite pork cuts, cured and smoked ham and bacon, and fresh pork sausage (100 g portion) (Buege et al., 1991; National Live Stock and Meat Board, 1988, 1991)

	Pork, composite of all cuts (lean-only, cooked)	Cured ham, boneless		Cured bacon (broiled, pan fried, or roasted)	Fresh pork sausage (cooked)
		95% lean (roasted)	Regular (roasted)		
Total, fat (g)	9.32	5.53	9.02	49.24	31.16
Cholesterol (mg)	80.00	53.00	59.00	85.00	83.00
Energy (kcal)	208.00	145.00	178.00	576.00	369.00
Fatty acids					
Saturated, total (g)	2.68	1.81	3.12	17.42	10.81
C_{10}	0.01	0.02	0.03	0.08	0.12
C_{12}	0.01	0.02	0.02	0.07	0.09
C_{14}	0.10	0.09	0.15	0.62	0.45
C_{16}	1.74	1.12	1.86	10.98	6.53
C_{18}	0.82	0.57	1.05	5.67	3.62
Monounsaturated, total (g)	3.63	2.62	4.44	23.69	13.90
$C_{16:1}$	0.32	0.24	0.45	1.73	1.09
$C_{18:1}$	3.24	2.38	4.00	21.96	12.81
$C_{20:1}$	0.07	—	—	—	—
Polyunsaturated, total (g)	0.39	0.54	1.41	5.81	3.81
$C_{18:2}$	0.35	0.48	1.17	4.89	3.28
$C_{18:3}$	0.01	0.06	0.24	0.79	0.54
$C_{20:4}$	0.03	—	—	0.13	—
Fatty acids as % of total fat					
Saturated	28.76	32.73	34.59	35.38	35.69
Monosaturated	38.95	47.38	49.22	48.11	44.61
Polyunsaturated	4.18	9.76	15.64	11.80	12.23

Table 6.7. Lipid composition of composite of all retail cuts of lamb and veal cuts and sausage products containing beef and pork (100 g portion) (National Live Stock and Meat Board, 1988)

			Sausage products		
	Lamb composite of all cuts (lean-only, cooked)	Veal composite of all cuts (lean-only, cooked)	Frankfurters	Dry and semi-dry thuringer, cervelat, and summer sausage	Luncheon meat
Total fat (g)	9.52	6.58	29.15	29.93	32.16
Cholesterol (mg)	92.00	118.00	50.00	68.00	55.00
Energy (kcal)	206.00	196.00	320.00	347.00	353.00
Fatty acids					
Saturated, total (g)	3.40	1.84	10.76	12.03	11.59
C_{10}	0.02	—	0.08	0.05	0.08
C_{12}	0.03	0.01	0.06	0.05	0.05
C_{14}	0.30	0.12	0.53	0.72	0.48
C_{16}	1.83	1.07	6.45	6.83	7.09
C_{18}	1.17	0.63	3.65	4.38	3.89
Monounsaturated, total (g)	4.17	2.35	13.67	13.93	15.09
$C_{16:1}$	0.28	0.21	1.31	1.79	1.35
$C_{18:1}$	3.86	2.11	12.36	12.14	13.74
$C_{20:1}$	0.03	0.03	—	—	—
Polyunsaturated, total (g)	0.62	0.59	2.73	1.89	3.74
$C_{18:2}$	0.51	0.45	2.34	1.56	3.16
$C_{18:3}$	0.06	0.03	0.39	0.33	0.58
$C_{20:4}$	0.06	0.11	—	—	—
Fatty acids as % of total fat					
Saturated	35.71	27.96	36.91	40.19	36.04
Monounsaturated	43.80	35.71	46.90	46.54	46.92
Polyunsaturated	6.51	8.97	9.36	6.31	11.63

Table 6.8. Lipid composition of some beef and pork variety meats (100 g portion) (National Live Stock and Meat Board, 1988)

	Beef			Pork		
	Liver (braised)	Heart (simmered)	Tongue (simmered)	Liver (braised)	Heart (simmered)	Tongue (simmered)
Total fat (g)	4.89	5.62	20.74	4.40	5.05	18.60
Cholesterol (mg)	389.00	193.00	107.00	355.00	221.00	146.00
Energy (kcal)	161.00	175.00	283.00	165.00	148.00	271.00
Fatty acids						
Saturated, total (g)	1.91	1.68	8.93	1.41	1.34	6.45
C_{10}	—	—	—	—	—	0.02
C_{12}	—	—	—	—	0.01	0.09
C_{14}	0.06	0.13	0.84	0.02	0.10	0.34
C_{16}	0.60	0.70	5.91	0.53	0.69	4.13
C_{18}	1.22	0.77	2.19	0.84	0.52	1.87
Monounsaturated, total (g)	0.65	1.25	9.47	0.63	1.18	8.79
$C_{16:1}$	0.05	0.10	0.64	0.03	0.11	0.70
$C_{18:1}$	0.60	1.05	8.84	0.56	1.05	7.89
$C_{20:1}$	—	—	—	—	0.02	0.17
$C_{22:1}$	—	—	—	0.04	—	—
Polyunsaturated, total (g)	1.07	1.37	0.78	1.05	1.30	1.93
$C_{18:2}$	0.45	0.90	0.58	0.42	0.89	1.84
$C_{18:3}$	—	0.02	—	0.04	0.10	0.09
$C_{20:4}$	0.29	0.45	0.20	0.53	0.31	—
$C_{20:5}$	—	—	—	0.04	—	—
$C_{22:6}$	0.25	—	—	0.03	—	—
Fatty acids as % of total fat						
Saturated	39.06	29.89	43.06	32.04	26.53	34.68
Monounsaturated	13.29	22.24	45.66	14.32	23.37	47.26
Polyunsaturated	21.88	24.38	3.76	23.86	25.74	10.38

Females generally are not gonadectomized, but, if they are, they have even more fat than do castrated males. In cattle and sheep, fat deposition in castrated males and gonadally intact females begins about the same age, but the rate of deposition is more rapid in females. In pigs, fat deposition also begins at the same age in castrated males and intact females, but, in contrast to cattle and sheep, the rate in castrated males is more rapid than in females. Although the total fat content varies between red meat cuts from animals of different genders, cholesterol content and especially fatty acid profile differ very little. The small differences in cholesterol content are a reflection of the total fat content.

Breed and Body Type Effects

In general, the beef breeds (bred for meat production) have more intramuscular fat, and its deposition begins at younger ages in beef cattle than in dairy cattle (bred for milk production). Within the breeds of beef cattle, type, i.e., small-framed, early-maturing versus large-framed, late-maturing cattle, has a great effect on fat content of the carcass (Boggs and Merkel, 1990). Late-maturing cattle have less fat, including intramuscular fat, than do early-maturing cattle because fat deposition is a late-occurring event. Early-maturing cattle attain mature size at younger ages than do late-maturing cattle. Consequently, at normal market weights, early-maturing cattle are fatter. The continental European breeds of cattle are large-framed and late-maturing and are very lean compared with the traditional British beef breeds, which were used almost exclusively for beef production in the United States before the 1970s. Of the breeds of cattle, Angus begin deposition of intramuscular fat at about 9 to 10 months of age, whereas deposition begins in Hereford, Holstein, and the continental European breeds of cattle at about 14 to 15 months of age or even later (Allen et al., 1976; Schroeder, 1987). At slaughter, cattle average about 18 to 20 months of age; thus, intramuscular fat content varies greatly among breeds. The breed effects on intramuscular fat deposition are, to a large extent, related to differences in maturity, i.e., early versus late maturing.

The breed and type criteria also generally apply to pigs and sheep, but the differences are not as pronounced as those for cattle. Tremendous strides have been made through genetic selection for large-framed animals and/or through crossbreeding programs to produce later-maturing cattle, sheep, and pigs. As a consequence, fat has been decreased markedly in today's meat animal production systems.

The fatty acid profile and cholesterol content differ very little between breeds of cattle fed similar diets and to the same degree of fatness (Larick and Turner, 1989; Pelton et al., 1988; Turner et al., 1989). Additionally, cholesterol content and fatty acid profile was found not to differ between beef from three different frame sizes of cattle (Lust, 1989). Similarly, little or no differences in cholesterol and fatty acid profile have been reported between breeds of sheep and swine.

Nutrition and Management Effects

Deposition of intramuscular fat seems more dependent on age of cattle, sheep, and pigs than on diet composition when diets are nutritionally adequate (Allen et al., 1976). This observation obviously reflects the late development of intramuscular fat. In cattle, however, total intramuscular lipids were greater in those fed in the feedlot when compared with those fed on the range (Miller et al., 1981). Generally, cattle and lambs fed low-energy forage diets have less intramuscular fat than do those fed high-energy grain diets. Pigs, on the other hand, are fed grain diets and, thus, intramuscular fat is not limited by diet. Intramuscular fat tends to increase in all red meat species with increasing age, once deposition of that fat has begun.

Payment for cattle based on quality grade, i.e., sufficient marbling to achieve the U.S. Choice grade (approximately 5% intramuscular lipid) results in carcasses that have in excess of 30% total fat. Recent data indicate that 3% of intramuscular lipid will ensure acceptable palatability of beef (Savell and Cross, 1988). This fat percentage is equivalent to lamb and beef in the lower range of Good and Select grades, respectively, and pork from the U.S. No. 1 grade (Table 6.4). A 3.5-fold increase intramuscular fat from 3 to 10.5% occurs over the grades of beef from Select to Prime. Palatability traits are only improved by 14% over these grades, but the kilocalories from fat are increased from 27 to 94.5 per 100 g serving.

Accelerated beef production, i.e., feeding calves concentrate diets immediately after weaning without any "backgrounding" period, results in younger cattle at slaughter and less carcass fat, including intramuscular fat. The palatability of such beef is very acceptable (Lust, 1989). This management system is not a common beef production practice but, if implemented, would decrease markedly the fat content of beef.

The fatty acid composition of meat is determined by the fatty acid composition of the diet the animal has consumed as well as by the de novo synthesis of fatty acids in the body. Nonruminants, such as pigs, chickens, and fish, tend to deposit the dietary fatty acids in much the same form as ingested; that is, they neither saturate nor desaturate them. In ruminants, on the other hand, the microorganisms present in the rumen of cattle and sheep increase the saturation of the fatty acids ingested. Because the fatty acids of plants are highly unsaturated, and because these fatty acids are not altered in the digestive tract of pigs and chickens who consume mainly grains, their fat is more unsaturated than those of beef and lamb/mutton. Thus, in all nonruminant species, at least, the fatty acid profile in meat is a blend of fatty acids from the diet and de novo synthesis. Nonetheless, dietary lipids markedly influence the fatty acid composition of the fat of nonruminants, and the more saturated fat of ruminants is largely attributable to saturation of fatty acids by rumen microorganisms. Although the fatty acid profile of the lipids of cattle and sheep is less affected by dietary lipids than that in pigs, the polyunsaturated fatty acids of both the triacylglycerols and phospholipids increase significantly in ruminants fed forage diets compared with primarily grain diets (Larick and Turner, 1989). In addition, pasture-fed beef and lambs have increased odd-numbered fatty acids, notably $C_{15:0}$.

Some plant seed oilmeals (e.g., soybean and linseed meals) fed to livestock provide the ω-3 fatty acid, linolenic acid. This ω-3 fatty acid is also present in canola oil meal and fishmeal, which also are fed to livestock, although to a lesser extent than is soybean meal. Diets fed to livestock that contain these oilseed meals increase the concentration of linolenic acid in meat, and the increases are most pronounced in the fat of pigs compared with that of ruminant species, such as beef and sheep (Romans et al., 1989). Although much less pronounced in ruminants, the increase in linolenic acid in the fat of all species parallels the concentration in the diet.

If fatty acids are provided with protective coatings to prevent their saturation by the microorganisms in the rumen, they can pass into the small intestine where the coating is degraded, and the fatty acids then are released, absorbed, and deposited in the adipose tissue depots of ruminants. In such instances, the fatty acid profile of the lipids of ruminants would parallel more closely the dietary lipids. This practice, however, rarely is followed in the production of beef and lamb in the United States.

The cholesterol content of beef has been reported to differ little between steers fed concentrate diets and those fed on pasture. Likewise, cholesterol content of lamb and pork has been observed to vary little because of dietary regimen. There is a trend for cholesterol content of beef, pork, and lamb/mutton to decrease slightly as fatness increases.

The growth promotants in general usages in meat animals, especially cattle, have little or no effect on fatty acid profile. Because these agents tend to decrease fat, including intramuscular fat, cholesterol content may be slightly higher than in those not provided with growth promotants.

Administration of somatotropin and beta-adrenergic agonists to cattle, sheep, and pigs have been reported to decrease fat deposition by 7 to 40% (Boyd and Bauman, 1989; Mersmann, 1989). The effects of these agents are dose-dependent, and somatotropin is much more effective than are the beta-adrenergic agonists in decreasing fat deposition. The fatty acid profile of fat from pigs fed the beta-adrenergic agonist, ractopamine, was only slightly altered when compared with controls (Engeseth et al., 1991; Lee et al., 1989; McKeith et al., 1990). Cholesterol content of pork from pigs fed ractopamine has been reported to be decreased by 7 to 10% (Engeseth et al., 1991; McKeith et al., 1990).

Administration of somatotropin to pigs also resulted in only slight alterations in fatty acid profile, with the proportion of polyunsaturated fatty acids tending to be increased (Beermann and Thiel, 1991; Prusa, 1989). No data for the effects of these agents on fatty acid profile are available for beef or lamb/mutton. Prusa (1989) found that pork muscles from pigs treated with somatotropin tended to have a higher cholesterol content, but Beermann and Thiel (1991) observed no effect of somatotropin on cholesterol content of pork muscle. No data on the effects of somatotropin on cholesterol content of beef or lamb/mutton are available.

Effects of Cooking

The greater the degree of unsaturation of fatty acids, the lower the melting point of the lipid. The lower melting point of the unsaturated fatty acids compared with that for saturated fatty acids results in greater losses of lipid during cooking. The higher the cooking temperature and the longer the cooking time, the greater the "cookout" of fat. Recently, Smith et al. (1989) reported that retail cuts of beef trimmed of all external fat had greater cookout of intramuscular fat compared with cuts with one-fourth inch of fat. Thus, trimming external fat from meat cuts before cooking would decrease the amount of intramuscular fat ingested. Renk et al. (1985) reported that little intramuscular lipid of beef loin steaks and pork loin chops was lost during cooking. Additionally, cuts with high amounts of marbling lost slightly more lipid than those with low marbling, and higher cooking temperatures (79°C) resulted in slightly greater losses of intramuscular lipid than did moderate temperatures (68°C).

Fatty acid profile seems changed little by cooking or by method of cooking. Likewise, cooking has a negligible effect on cholesterol content, and it is changed even less because of cooking method. The cholesterol content of cooked meat, however, is higher than in raw meat. Because of its presence in cell membranes, cholesterol becomes concentrated as water evaporates and fat "leaches out" during cooking. The increased cholesterol associated with cooking is related to the temperature and length of time the meat is cooked. Hoelscher et al., (1988) reported that 60 to 80% of the cholesterol in Prime, Choice, and Select grade beef is associated with cell membranes, and 20 to 40% with the stored lipid in adipose tissue. They also observed that cooking lowered the cholesterol content associated with the stored lipids, because it was leached along with the lipid; membrane cholesterol, however, was increased.

In ground beef patties containing 5, 10, 15, 20, or 25% fat, Cannel et al. (1989) reported that fat retention decreased as fat content of the patty increased, regardless of the cooking method. Also, fatty acid profiles of the patties changed little with increasing fat percentages, regardless of the cooking method.

The cholesterol content of cooked retail cuts of beef, lamb, and pork are similar (86, 92, and 80 mg per 100 g portions, respectively). Retail cuts of veal have little intramuscular fat and hence have a slightly higher cholesterol content (118 mg) than do beef, lamb, and pork. These data reflect the fact that cholesterol is associated with membranes and is diluted as protein and lipid accumulate in muscle during growth of the animal. The cholesterol content of cooked variety meats of beef range from 107 mg per 100 g in tongues to 389 mg in liver. Beef heart contains 193 mg per 100 g of cooked portion. Corresponding cholesterol contents of pork variety meats are 146, 355, and 221 mg per 100 g of cooked portion, respectively. Thus, it is evident that the cholesterol content of variety meats exceeds that of the retail cuts. The cholesterol content of sausage products, most of which contain beef and pork, is lower than the content of the respective retail cuts, reflecting the dilution by nonmeat ingredients. Most sausage products contain between 45 and 68 mg of cholesterol per 100 g. Sausage containing liver or heart obviously has greater cholesterol contents (e.g., braunschweiger = 158 mg per 100 g).

Factors Affecting Fat Deposition, Cholesterol Content, and Fatty Acid Profile of Fish

The fat content of fish varies with species, season, physiological status, diet, location in the body, and age (Kinsella, 1988). The fat content of some species can fluctuate as much as 10%, depending on the season of the catch. Fat content is highest during cold seasons. Females have more fat than do males, and fat content increases with age of the fish. As with other animal species, fat content parallels dietary energy intake.

The fatty acid composition of fish varies with species, season of catch, and diet (Kinsella, 1988). In general, fish have a high content of polyunsaturated fatty acids, especially of the ω-3 family, and notably $C_{20:5}$ and $C_{22:6}$. The highest percentages of the polyunsaturated ω-3 fatty acids are found in those species of fish whose diet consists largely of phytoplankton (Cowey, 1988). The ω-3 fatty acids are contained in the photosynthetic membranes of phytoplankton, and consequently phytoplankton provides a rich source of these polyunsaturated fatty acids for fish subsisting on mainly vegetative diets (Cowey, 1988). Phytoplankton constitutes a larger proportion of the diet of marine fish than freshwater fish, which is reflected in the differences in their ω-3 fatty acid content. Like the nonruminant red meat species, fish do not alter dietary lipids, and their fatty composition parallels the fatty acids in the diet (Watanabe, 1982).

The cholesterol content of finfish tends to increase with fat content (Kinsella, 1988). Lean finfish generally have less cholesterol (usually less than 45 mg) than do fatty fish. The cholesterol content of the common finfish ranges from 40 to 90 mg per 100 g of cooked portion. The cholesterol content of canned fish (e.g., tuna) varies, depending on whether packed in oil or water. Tuna packed in oil contains 18 mg of cholesterol per 100 g portion, whereas that packed in water contains 35 mg. Tuna packed in oil, however, contains 199 kcal per 100 g portion; that packed in water has 130 kcal per 100 g. Shellfish tend to have higher cholesterol contents than do finfish. Crustaceans (e.g., crab, lobster, and shrimp) contain 53 to 195 mg per 100 g of cooked portion. Of these, shrimp has the highest content. Mollusks (e.g., clams, scallops, and oysters) contain 61 to 165 mg per 100 g of cooked portion.

The cholesterol content of fish varies with the season of catch. It can vary by as much as 90 to 100%. Cholesterol content is lowest at the end of the winter months and increases to its highest content in the fall months (Krzynowek, 1985). The cholesterol content of minced fish is greater than that of the corresponding fillets, e.g., 80 versus 40 mg per 100 g in cod and whiting (Kinsella, 1988). Cooking has little effect on cholesterol content of fish; the slight increase following cooking is associated with the water loss (Kinsella, 1988).

Imitation seafood products, notably shrimp and crab analogs fabricated from surimi, are gaining steadily in popularity. Surimi is a proteinaceous product made by extracting salt-soluble proteins from minced fish flesh with sodium chloride. Most of the soluble proteins are removed by washing. Sucrose or other sugars and/or sorbitol are added as cryoprotectants, and phosphate is added to enhance bind and textural properties. The protein mince is "formed" to mimic shapes of natural seafood products, and, when heated, the proteins gel and become resilient and springy to provide imitation analogs with textural properties resembling natural products.

The surimi-based analogs of shrimp and crab meat are much lower in fat and cholesterol content than their corresponding natural meat. The crab analog has more than 60% less cholesterol than does natural crab leg meat; the shrimp analog has an even greater decrease (more than 75%) in cholesterol content (Lanier et al., 1988). These data are presented in Table 6.9. Other imitation fish products are available, but no composition is available for them.

Table 6.9. The lipid, energy, and cholesterol content of natural shrimp and crab and their manufactured analogs (100 g portion) (Lanier et al., 1988)

	Natural		Imitation	
Item	Shrimp	King crab	Shrimp	King crab
Lipid (%)	1.08	1.54	0.25 — 1.80	0.20 — 1.30
Energy (kcal)	99.00	96.00	90.00 — 100.00	73.00 — 98.00
Cholesterol (mg)	195.00	53.00	30.00 — 45.00	4.00 — 20.00

7 Altering Fat Composition of Dairy Products

Summary

Altering the fat composition of dairy products can be accomplished by a multitude of different processes. One must be cognizant of marketing needs, the effect of federal and state regulations, economic constraints, and technological opportunities before proceeding to modify the fat content of a standard dairy product. Technology has provided the opportunity to use a wide variety of processing systems, such as enzymatic conversions to extractions by supercritical solvents, to enhance the ability to produce a plethora of products. Biotechnology offers new promise for the future. It creates an opportunity to address issues (e.g., saturation) not available by using current technologies at potentially favorable costs and conditions. If the dairy industry is to achieve any success in utilizing its abundant milk fat, technological modifications will have to be undertaken to improve milk fat's utility as a food ingredient of choice.

Introduction

Milk has been disassembled into its various components ever since the beginning of recorded history. It was a matter of simple observation that, if milk was allowed to stand, the cream rose to the top. Early man learned to extract the butterfat by mechanical means and make butter or butteroil. Altering the fat composition of dairy products can be accomplished by multiple means.

This chapter will delineate and discuss the physical, chemical, and biological means of alteration and relate some comments concerning regulations, pricing, and future product development trends and opportunities.

Federal Regulations

To obtain a perspective on altering fat composition, one should understand that dairy products is a category of foods that is highly regulated. Nearly all dairy products have a Standard of Identity, which generally has as its basis a minimal concentration of fat. To alter fat composition, particularly to decrease the fat composition of a standard dairy product, one is not allowed to use the usual and common name. Thus, whole new categories of standards need to be established or newly named to effectively translate the identity of the new product to the consumer.

For years, the cheese industry has balked at the restrictions that federal standards place on cheese production and marketing. For instance, minimal requirements for fat and moisture in the Standard of Identity for cheddar cheese do not allow labels to state "reduced fat cheddar cheese." In 1987, Kraft introduced a line of reduced fat cheeses to more fanfare than the company may have wanted. The Food and Drug Administration (FDA) did not act because the State of Wisconsin decided to take up the banner to oppose Kraft. Initially, Wisconsin officials withheld shipments but later quietly rescinded this action with a decision to allow the new products.

Other companies, most notably Dorman Roth Foods, have avoided confronting the standards by choosing other names and descriptions of their products. Dorman Roth, which has been selling "light" cheeses for several years, tiptoed around the issue by giving its products carefully chosen names like "Chedda Delite" and "Slim Jack".

Food labels and standards have been a matter of controversy for nearly a century. United States Department of Agriculture (USDA) personnel review every meat and poultry product label before it can be used and require an ingredient statement even if the product is covered by a Standard of Identity. In 1985, 143,000 labels were approved and 19,000 were disapproved (Hettinga, 1988a). The FDA does not review labels nor does it require ingredient statements for standardized foods. Dietary cholesterol is present only in animal products. It is now widely accepted that a number of Americans should probably decrease their cholesterol intake. Current FDA regulations, however, are restrictive as to the inclusion of cholesterol information on product labels. The new proposed rules above would encourage the voluntary declaration of cholesterol and fatty acid contents on labeling to assist individuals in lowering their intake of these substances, should they so desire, as well as to assist those individuals who have been directed medically to modify their intake. Again, developing processing techniques for cholesterol removal would affect dairy products' labeling and standards and, of course, consumer attitudes.

Proper market signals and information are just as important to consumers as they are to producers. Information on the label or as conveyed by Standards of Identity is a basic starting point for consumers wishing to exercise informed choice in the marketplace.

Processing Methods

The most basic and oldest processing method is cream separation. Ancient people are known to have used milk freely, and it is probable that they at times used cream that rose to the top of the milk that had been held for some time in containers, although there is little in ancient literature to suggest such use as common. It is well established that in early times, butter was produced by churning milk. Thus, in one of the oldest parts of the Bible occurs the statement, "surely the churning of milk bringeth forth butter." Separation of cream from milk is possible because of a difference in specific gravity between the fat and the liquid portion or serum. Whether separation is accomplished by gravity or centrifugal methods, the result is dependent upon this difference. An example of simply removing fat are products for an expanding market for all-dairy, sour cream alternative products with half the fat content of standard sour cream. The industry has responded, in some cases, by simply replacing the 18% butterfat cream ingredient in the manufacturing process with a 9% butterfat starting ingredient. Land O'Lakes, Inc. has pioneered this category with a dairy product that used proprietary processing in combination with cream, skim milk, and whey proteins to produce a product with less than half the butterfat content of traditional sour cream while still maintaining the taste and texture expected from a full-fat product.

If one reviews the entire dairy case, basically all existing Standard of Identity dairy products technically can be produced in a lower fat alternative form. The next generation of fat substitutes, such as Simplesse™ or olestra, could offer the dairy industry even greater flexibility in product development. One excellent fat replacer that exists today and is a component of Simplesse™ is whey protein (Dziezak, 1989). Dairy proteins provide the opportunity to replace some of the fat in dairy products while still ensuring that the product would qualify for the Real Seal®. The use of existing dairy proteins as ingredients that deliver functionality, nutritious protein, calcium, and a healthy image and that can be modified by new processing conditions will play an increasingly important role in future dairy products. Outside of the butter/margarine/spreads category, future fat replacers probably will have a minor impact on existing dairy products, because it is already possible to formulate dairy products into lower fat alternatives.

Fractionation

The art of fractional crystallization for the purification of fats on a commercial scale is a relatively recent innovation. Fractional crystallization is a thermomechanical separation process wherein component triacylglycerols of fats and oils are separated, usually as a mixture, by partial crystallization in a liquid phase. In the process, three successive stages are recognized: (1) cooling of liquid or melted triacylglycerols to produce nucleation, (2) growth of crystals to a size and shape that permit efficient separation, and (3) separation, isolation, and purification of resultant solid and liquid phases (International Dairy Federation, 1989).

Several methods for the fractional crystallization of fats and oils currently are practiced on a commercial scale in combination with procedures and equipment to effect separation and isolation. Fractionation by thermal crystallization, steam stripping, short-path distillation, supercritical fluids, or crystallization can achieve fat alterations of significance to the dairy industry. Milk fat is a mixture of triacylglycerols of a range of molecular weights and degree of unsaturation, exhibiting a broad and variable range of melting points and other physical properties. Milk fat is an important component of most dairy products, but it has been consumed traditionally for the most part as butter.

Because the physical properties of milk fat influence the rheological properties of dairy products, especially butter, there has been considerable interest in the modification of milk fat by physical and chemical means. Economic fractionation of milk fat into oil and plastic fat fractions will facilitate an increased utilization of milk fat in many food applications, such as chocolate, confectionery, and bakery products, and in developing new convenient (spreadable) and dietetic (decreased cholesterol, fatty acid variable composition) butter or butterfat-containing products.

Fractionation by Thermal Crystallization

Milk fat exhibits a wide melting range from about −10°C to about +50°C. This provides the possibility of crystallizing out a series of glyceride fractions at temperatures below their melting points. Suitable sizes of crystals are developed by controlling cooling of the melt, and the crystals are separated from the liquid phase by filtration or centrifugation. The fractionation of milk fat by melt crystallization has been studied extensively (Amer et al., 1985; Makhlouf et al., 1987; Wilson, 1975). The general conclusions from these investigations were: the short-chain triacylglycerol and the short-chain fatty acids, as well as the unsaturated long-chain fatty acids, were enriched in the liquid fraction; the efficiency of molecular size separation in the melt crystallization process was poor; and the flavoring compounds, pigments, vitamin A, and cholesterol were concentrated in the liquid fraction. Furthermore, melting behavior of milk fat fractions with potential application in the food fat formulations have been identified.

One industrial process in practice for the fractionation of milk fat is the Tirtiaux system, which is a semicontinuous bulk crystallization process. The Tirtiaux dry fractionation process enables one- or two-step fractionation of butteroil at any temperature ranging from 50°C to 2°C (Hettinga, 1988b). The milk fat fractions thus obtained can either be used as such, or the fractions can be blended in several proportions for use as ingredients in various food fat formulations or for the use of preparing spreadable butter (Bumbalough, 1989).

Fractionation by Steam Stripping or Deodorization

When margarine came into use as an economical substitute for butter, odorless and tasteless fats and oils became highly desirable. Carefully rendered bovine and porcine fats were relatively neutral in flavor. The flavor these fats possessed was sufficiently animal-like that at one time they were considered to be not too obtrusive as a butter substitute. Even today, some food processors use tallow as a frying fat, preferring the odor and flavor produced to that of a bland shortening. Vegetable fats, on the other hand, tend to have naturally strong flavors quite foreign to that of butter.

Steam deodorization is feasible because of the great differences in the volatility between the triacylglycerols and the substances that give oils and fats their flavors and odors. It is essentially a steam distillation whereby volatile odoriferous and flavored substances are stripped from the relatively nonvolatile oil at temperatures below those damaging to the oil. The application of decreased pressure during the operation protects the hot oil from atmospheric oxidation, prevents undue hydrolysis of the oil by water, and greatly decreases the quantity of steam needed (Swern, 1964). However, the process results in a completely tasteless product.

Fractionation by Short-Path Distillation

Distillation at moderate vacuum is characterized by the use of conventional distillation equipment at its lower pressure limit. Short-path and molecular distillation often are grouped together as unobstructed path or high vacuum distillation; the difference between them is one of dimensions and operating conditions. Short-path distillation is a relatively known process and consists of evaporation of molecules into a substantially gas-free space. The controlling factor is the rate at which the molecules escape from the heated surface of the distilling liquid and are received by the cooled condenser surface (Arul et al., 1989; Bracco, 1980). Milk fat, being a mixture of triacylglycerols differing in molecular weights, volatility, and intermolecular interaction energies, is an ideal candidate of effect separation of triacylglycerol by short-path distillation (International Dairy Federation, 1989). Milk fat triacylglycerols that have high boiling points can be viewed with pessimism because of the requirement of high temperatures (Arul et al., 1989). Experiments showed that short-path distillation effects a very high degree of molecular weight separation and is superior to melt crystallization as a process for molecular separation of triacylglycerols (Arul et al., 1989; International Dairy Federation, 1989). Short-path distillation thus offers an excellent opportunity to obtain fractions from milk fat with distinctive chemical and physical properties. Development of dietetic butter enriched in short- and medium-chain triacylglycerols is possible with high proportions of liquid and intermediate fractions obtained from this process. Stripping of cholesterol and recovery of flavoring compounds are other attractive features. In spite of all the positive features, the short-path distillation process suffers from high thermal requirements.

Fractionation by Supercritical Fluids

Supercritical fluid extraction (SFE) has obtained extensive attention recently, especially for the removal of cholesterol from milk fat. The SFE is a state-of-the-art unit operation that exploits the dissolving power of supercritical fluids at temperatures and pressures above their critical values. It involves the use of a gas elevated above its critical pressure and temperature as a solvent for selected components of a solid or liquid mixture. Under supercritical conditions, the solvent displays an increase in density, approaching that of a liquid but retains the diffusivity associated with a gas. These properties allow the supercritical fluid to penetrate a structure of a material to be separated, dissolve soluble components, and carry them out of the extraction vessel. The extract can be recovered easily from the solvent by manipulation of pressure and/or temperature conditions such that they become insoluble and precipitate out of solution. The solvent can be vented off or recirculated through the extraction vessel.

A number of advantages have been cited for SFE compared with conventional extraction techniques currently used in the food industry. These include decreased energy costs, higher yields, better quality products owing to lower operating temperatures, and elimination of explosive or toxic solvents. It is anticipated that the use of SFE and its range of applications will continue to grow during the coming years (Hettinga, 1988a).

Supercritical carbon dioxide is receiving increased attention from the food industry as a solvent to replace hydrocarbons and chlorinated hydrocarbons currently used in vegetable oil extraction, decaffeinating coffee, and spice extraction. It has one obvious advantage in food in that it is nontoxic in any concentration. Its low critical temperature (31°C) combined with its pressure-dependent dissolving power make it attractive for separating particularly heat-labile flavor and aroma constituents at near-ambient temperatures.

Supercritical carbon dioxide has been used for the SFE of oils from soybeans (Friedrich et al., 1982), corn, and cottonseed (List et al., 1984). The oil from these three oilseeds obtained by SFE, compared with hexane-extracted oil, was reported to be much less pigmented, require less refining, and have greater resistance to oxidative rancidity (Friedrich and Pryde, 1984). The last trait was attributed to the lower concentrations of free fatty acids, free iron, and phosphorus as phospholipids and the higher concentration of tocopherols in the oil after SFE. This observation indicates that supercritical carbon dioxide is able to remove a specific lipid fraction while leaving the other fractions intact.

The main structural units of milk are fat globules, casein micelles, globular proteins, and lipoprotein particles (Walstra and Jenness, 1984). Fat globules are the primary source of lipids in milk. Their structure and composition are exceedingly complex. A typical fat globule is probably 2 to 3 mm in diameter. Its core is composed of triacylglycerols (99%), with the remaining 1% composed of cholesterol and trace amounts of other lipid components.

German, United Kingdom, and American researchers (Biernoth and Merk, 1985; Makhlouf et al., 1987; Supercritical Processing, 1988) have reported the successful SFE fractionation of anhydrous milk fat, separating distinct fractions including nearly all the cholesterol. To effectively remove the cholesterol from the milk lipid system, the fat globule must be penetrated, because it contains the largest deposit of cholesterol in milk. The cholesterol, however, must be removed from the fat globule without destroying any of the globule's ability to function. Therefore, a crucial factor affecting the ability of the supercritical fluid to extract the lipids from the fat globule may be the status of the fat globular membrane.

The SFE offered an excellent opportunity for obtaining milk fat fractions with distinctive differences in chemical and physical properties that could satisfy the requirements of many food applications. However, this process is energy and capital intensive.

Fractionation Using Solvents

Fractionation by crystallization using solvents, such as acetone, commonly is employed in the laboratory. Separation of fat crystals from organic solvents is accomplished easily, and the fractions obtained can be recrystallized and purified easily. This method, however, has not found industrial application because of the loss of flavor compounds of milk fat, pigment alteration, and the problem of solvent residues.

Solvent extraction and the problem of residues is generally unacceptable as a process for the manufacture of dairy products. This would be especially true for Standard of Identity dairy products, such as butter, from which the cholesterol has been removed by solvent extraction.

Separation by Absorption

There have been a number of reports, as well as involvements of companies, in the development of processes whereby cholesterol can be removed by selective absorption onto selective compounds (Shishikuva et al., 1986). These compounds range from activated carbon to bile sequestrants. Several companies, institutes, and universities are actively researching this approach to remove cholesterol from milk fat. For instance, the New Zealand Dairy Research Institute has developed a process for the removal of total cholesterol from milk fat based on the use of absorbent materials. Patents have been applied for worldwide and have been granted in New Zealand and South

South Africa (personal communication).

A major shortcoming of an absorption process is the lack of general selectivity of similar components. For instance, many of the flavor and color components are removed from the milk fat and generally cannot be recovered efficiently.

Enzymatic Conversion

A hypothesis exists that the cholesterol reductase from *Eubacterium* species can be used to convert the cholesterol in fluid milk to products (primarily coprostanol and cholestanol) that are either poorly absorbed or completely unabsorbed in the human intestine and will, therefore, be excreted. McDonald et al. (1983) reported that the major end product of cholesterol reduction (coprostanol) by *Eubacterium* species indeed is absorbed poorly by humans. Furthermore, a lesser amount of cholesterol would be available in the intestine for oxidation to compounds that are potentially carcinogenic. Products from the chemical reduction of cholesterol are not carcinogenic. Conversion of cholesterol to chemically reduced and poorly absorbed compounds therefore should decrease the concerns of cholesterol-conscious people about consuming milk and other dairy products (Spalding, 1988).

Currently, the work for extracting, purifying, and concentrating cholesterol reductase from species of *Eubacterium* is being performed by researchers at Iowa State University (Spalding, 1988). In addition to extraction of the cholesterol reductase, the University of Minnesota is working on genetically transferring the gene that provides the ability to specifically produce cholesterol reductase into a lactic dairy culture (Harlander, 1988).

Milk Fat Texturization

Texturization is a process, normally a mechanical treatment, which is applied to fat products to obtain certain textural properties, such as spreadability, plasticity, and smooth appearance. It always has been a wish to improve the spreadability of traditional, churned butter at refrigeration temperature. One method used for improving spreadability is vigorous kneading of prepared butter. Another process that was previously commented on to improve spreadability is use of thermal fractionation (Tirtiaux system).

When a milk fat is cooled rapidly and crystallized under vigorous agitation so that the final crystal and a large proportion of the secondary structure are formed before the product leaves the crystallization equipment, the result will be a plastic product. High plasticity and firmness are required for fats used for roll-in or puffed pastry. The stearine (high melting point triacylglycerol fraction) fraction from the Tirtiaux or dry fractionation process of milk fat is an excellent raw material for puff pastry (International Dairy Federation, 1989).

Interesterification of fats is a chemical process in which the distribution of fatty acids among the triacylglycerols is altered. This process has not been applied to milk fat because of associated high costs and because the process produces many by-products, such as off flavors, that require removal (Kalo, 1989).

Hydrogenation of several fats and oils is used extensively in industry but generally is not applied to butterfat because the cost of raw materials argues against its use as a feedstock. Given the criticism directed at milk fat because of its saturated nature, there seems to be little future in increasing the degree of saturation by means of hydrogenation. The reverse procedure, desaturation or dehydrogenation, offers more attractive prospects. Some thought already has been given to the possibility of increasing the proportion of unsaturated fatty acids through enzymatic treatments.

Factors Affecting the Alteration of Fat Content

Technology

As noted in the previous section, multiple technologies have been or are being developed to alter the composition of fat in dairy products, but the rate at which one or more play a major role in the development of a new dairy product will depend on the efficiency of alteration and/or separation, economics of capitalization, and market opportunities.

Component Pricing

Historically, the component values of producer milk have varied according to the market demand for butter. This value has ranged from a high of 82.9% of total milk value at support prices to 48.8% in the early 1980s. The actual average price received by farmers tends to average approximately $1 per hundred weight above the support price, with this additional value attributable to the nonfat portion of milk. Even though the price placed on the fat value varies, the perception exists that the most valuable portion of milk is the fat, and farmers are paid for that fraction. This tends to stimulate the production of milk fat, to select cows that produce milk with high concentrations of fat, and to feed for the production of milk fat.

Component pricing would not drastically change prices but would significantly alter perceptions.

Standards of Identity

Standards of Identity protect natural dairy foods and help dairy foods maintain their healthful, fresh image. The introduction of low-fat dairy food with a variety of names, however, has created confusion in the minds of consumers. The decision whether to give such products low-fat names based on traditional names, or to initiate new names, has confused the industry. The fragmentation of the dairy industry over this issue has decreased the incentive for the dairy industry to respond to consumer demands for low-fat products and gives the impression that the industry is attempting to ignore or resist the recommendations to decrease fat consumption.

Conclusion

If the dairy industry is to achieve any success in utilizing its abundant milk fat, technological modifications will have to be undertaken to improve milk fat's utility as a food ingredient of choice. In terms of surplus butterfat, it would be both practical and profitable to extract butter flavor and concentrate it. This product then could be used in pastries, cooking oils, breads, edible creams, and imitation dairy products.

Compared with other natural fats, milk fat has certain properties that offer a good starting point for developing new milk fat products: (1) multiple fatty acid, triacylglycerol, and vitamin composition; (2) phospholipids and lipoproteins; (3) excellent taste and aroma; and (4) some special physical properties. The problem is the high price that decreases its competitiveness in relation to vegetable fats and oils.

Fractionation by crystallization, superfluids, or other technology are examples being applied commercially to milk fat to create favorably received new products. The essential purpose of milk fat application development is to adapt products to fit user purpose. Correctly performed crystallization, texturization, whipping, or other treatments offer numerous opportunities for improving the quality and applications of products based on milk fat.

Biotechnology offers new promise for the future. It creates opportunity to address issues (e.g., saturation) not available using current technologies at potentially favorable costs and conditions.

8 Altering Fat Composition of Red Meat and Fish Products

Summary

Meat products have been implicated in contributing to the incidence of heart disease. Recommendations from health care professionals, the Surgeon General, the USDA Dietary Guidelines, and the American Heart Association have emphasized consuming meat products with less fat. Recent purchasing trends suggest that consumers have become more conscious of the amount and type of fat in their diet and have tended to increase their purchases of foods that claim decreases in fat, calories, sodium, and cholesterol. Pork and beef carcasses have become leaner over the past two decades, and, in combination with trimming of retail cuts, over 42% of beef cuts recently surveyed had no external fat and the overall fat thickness for steaks and roasts from the chuck, rib, loin, and round averaged 0.14 in. To optimize palatability and limit fat in beef cuts and fresh pork cuts, an intramuscular fat content of 3% on an uncooked basis is necessary for minimal acceptable palatability, whereas no more than 7.3% fat should be present to meet the nutritional requirements for lean meat.

Decreasing the fat content of red meats and fish can be accomplished by (1) using leaner raw materials, (2) including non-meat ingredients in processed meats that serve as fat replacements, and (3) applying new process technologies that decrease the fat and cholesterol content of meat tissues. Increased use of more lean meats and fish may require removing individual muscle groups from carcasses and grouping according to product categories while also including less caloric dense meat ingredients, such as fat-reduced beef/pork, partially defatted chopped beef/pork, mechanically separated meats, and surimi. Fat replacements that offer a great deal of promise include ingredients such as added water or high-protein meat slurries; protein-based flours, concentrates or isolates; carbohydrate-based starches, gums, maltodextrins, or dextrins; and new-generation synthetic compounds.

Introduction

The Surgeon General's Report on Nutrition and Health (U.S. Department of Health, Education and Welfare, 1979; U.S. Department of Health and Human Services, 1988) originated in response to the increasing recognition that the most prevalent nutritional problems among Americans are the result of overconsumption and imbalances in dietary intake rather than of deficiencies of single nutrients (McGinnis and Nestle, 1989). By the mid-1970s, evidence had accumulated to indicate that many of the leading causes of death in the United States were linked in part to consumption of diets too high in fat, calories, salt, and alcohol and too low in fiber and other potentially protective dietary factors. Among the 10 leading causes of death in the United States, coronary heart disease, certain types of cancers, strokes, diabetes mellitus, and atherosclerosis have been associated with dietary excesses and nutrient imbalances. Nearly one-fourth of the U.S. population—about 34 million people—are overweight, and 13 million of these are severely obese. Data from the USDA's Nationwide Food Consumption Survey (1977 to 1978) indicated that Americans acquire about 37% of their total calories from fat and that 63% of the total dietary fat comes from animal products, specifically 42% from red meats, poultry, and fish. Most nutritionists and clinical scientific organizations recommend consuming no more than 30% of total calories per day as fat and limiting saturated fat to ≤10% of total calories. Thus, to improve the health prospects of many Americans and decrease the risk of chronic disease, the Surgeon General's Report (U.S. Department of Health and Human Services, 1988) concluded that the primary dietary priority for most Americans was to decrease their intake of fat (especially saturated fatty acids) and cholesterol by choosing foods such as vegetables, fruits, whole grains, fish, poultry, lean meats, and low-fat dairy products as well as to use food preparation methods that add little or no fat to the diet. The report also noted that food manufacturers could contribute to improving the

American diet by increasing the availability of palatable, low-calorie, or low-fat foods.

Fatty meats and meat products have been implicated in contributing to the incidence of heart disease, and recommendations from health care professionals have emphasized consumption of meat products with less fat. Recent purchasing trends suggest that consumers have become more conscious of the amount and type of fat in their diet and have tended to increase their purchases of foods that claim decreases in fat, calories, sodium, and cholesterol. In the case of meats, total red meat consumption on a per capita basis has declined from 71.6 kg in 1971 to 61.2 kg in 1989. Poultry and fish consumption, on the other hand, has increased from 22.3 to 39.0 kg and 5.2 to 7.2 kg, respectively. Because of these trends, meat products in the 1990s must be leaner, convenient, priced on the basis of relative value, perceived to be healthful, and, most importantly, taste good to meet consumer expectations. Results from the National Consumer Retail Beef Study (NCRBS) (Savell et al., 1987, 1989) indicated that consumers would purchase more beef if the fat was trimmed closely for retail display. In response, retailers began to offer beef with one-quarter in. or less external fat, and, in some cases, all the external fat and bones were removed from retail cuts.

Market potential for meat products with less fat and cholesterol has been estimated at $65 billion in sales volume, while the market value for shellfish has been projected to be $3.9 billion (Best, 1988). As a result, several methods and new technologies to decrease the fat and cholesterol content of meats and meat products have been investigated. Research for altering the fat composition of fresh and further processed meat products has concentrated primarily on changing the animal diet, trimming excess carcass fat, improving preparation methods (cooking), reformulating the meat base, evaluating new ingredients as fat replacements, and developing new technologies for removing fat and/or cholesterol.

Red Meat Products

Decreasing Fat Content

Trimming Excess Fat

Pork and beef carcasses have become leaner over the past two decades as a result of consumer demand for leaner products and an increased awareness of dietary issues. Savell et al. (1991) conducted a National Beef Market Basket Survey in 12 major cities across the United States and concluded that over 42% of beef retail cuts had no external fat and that the overall fat thickness for steaks and roasts from the chuck, rib, loin, and round was 0.14 in. When the data were compared with the 1986 USDA Agriculture Handbook 8-13, beef steaks and roasts had 27.4% less fat (Table 8.1) and ground beef had 10.2% less fat. On the average, ground beef had 33.4% less fat than the maximal fat percentage (30%) allowed by government regulations. Recent updates in the 1990 USDA Agriculture Handbook 8-13 now include the compositional data for closely trimmed retail cuts and lean ground beef.

Beef quality grade affects the yield, fat content, and

Table 8.1. Comparison of 1986 data[a] to national beef market basket survey (1988) for steaks and roasts (Savell et al., 1991)

		Total separable fat (external and seam)	
Retail cut	Percentage of total case weight	USDA Agriculture Handbook 8-13 (%)	National Beef Market Basket Survey (%)
Round steak	3.92	18.0	11.07
Top round steak	4.81	7.0	5.77
Eye of round steak	1.11	12.0	4.09
Bottom round roast	2.76	14.0	12.67
Eye of round roast	3.47	12.0	6.70
Round tip roast	4.16	14.0	9.71
Subtotal	20.23	—	—
Sirloin steak	2.48	20.0	14.61
Tenderloin steak	1.00	17.0	13.18
Top loin steak	5.75	24.0	15.17
Porterhouse steak	2.42	20.0	18.25
T-bone steak	2.16	23.0	17.08
Subtotal	13.81	—	—
Rib roast	5.45	27.0	22.15
Rib steak	2.18	27.0	22.27
Ribeye steak	4.27	17.0	20.68
Subtotal	11.90	—	—
Shoulder pot roast	2.78	20.0	14.73
Blade roast	9.69	18.0	14.53
Blade steak	5.18	18.0	13.25
Subtotal	17.65	—	—
Flank steak	1.74	5.0	4.93
Short ribs	4.37	32.0	14.85
Brisket	2.32	32.0	13.02
Shank cross-cut	.56	4.0	6.95
Subtotal	8.99	—	—
Total	—	18.18	13.70

[a]U.S. Department of Agriculture, 1986.

palatability of retail cuts. As the USDA quality grade increases from Select to Choice to Prime, the amount of intramuscular fat or marbling increases as does the amount of subcutaneous and intermuscular (seam) fat that must be trimmed from higher grading carcasses to meet retail specifications. Palatability of trimmed steaks, roasts, and pork loin chops, as determined by trained sensory panelists, increases with increased marbling (National Research Council, 1988; Savell et al., 1987). Consumers likewise rate Choice cuts better tasting, but fatter, and Select cuts leaner, but with less taste (flavor) or less desirable texture (juiciness and tenderness) (Savell et al., 1989). Overall, consumer acceptance for Choice and Select cuts is rated high but for different reasons. To optimize palatability and limit fat in beef cuts (and fresh pork cuts), an intramuscular fat content of 3% on an uncooked basis is necessary for minimally acceptable palatability, whereas no more than 7.3% fat should be present to meet the nutritional requirements for lean beef as outlined by the USDA Dietary Guidelines and the American Heart Association (National Research Council, 1988).

Removing excess subcutaneous and internal fat from higher grading beef carcasses immediately after slaughter (hot fat trimming) has been offered as a possible solution for providing more closely trimmed and leaner beef subprimals. Three obstacles, however, may prevent the adoption of this technique for decreasing fat: (1) trimmed carcasses may not be eligible for USDA yield grading, (2) hot carcass weight would be altered, affecting the current pricing system, and (3) seam fat in the chuck and rib differs across yield grades and gender classes (Savell et al., 1989).

Leaner Cuts and Raw Materials

The most obvious method for decreasing fat content in further processed red meat products is to use more defatted, boneless cuts or leaner raw materials. A notable example has been the production of "restructured" or "sectioned and formed" ≥95% fat-free hams or beef top rounds in which visible surface and seam fat have been removed, the tissues injected with a brine solution, and the product heat-processed to an internal temperature of about 70°C. Low-fat ham products are available at retail with 2.3 g fat, 18.6 g protein, 52 mg cholesterol, and 102 kcal per 100 g portion. Pastrami and corned beef products are also available with 1.8 g fat, 19.9 g protein, 43 mg cholesterol, and 96 kcal per 100 g portion.

Restructured steaks and chops offer processors greater opportunity to control fat content, portion size, and raw material costs but have different sensory characteristics as the fat content increases. Typically, muscles or trimmings from the square-cut chuck, round, or pork shoulder can be defatted, decreased in particle size, blended with ingredients (~1% salt, 0.3% sodium tripolyphosphate, and sufficient water to solubilize the ingredients), and shaped into an appropriate form. Mandigo (1981) indicated that fat concentrations of 20 to 25% in flaked steaks had desirable palatability traits but that 10 to 15% was preferred in sectioned and formed steaks. Restructured steaks and chops in the fat range of 10 to 14% have less cooking loss but tend to be slightly less tender and less juicy than those with more than 20% fat (Berry et al., 1985b; Costello et al., 1985; Mandigo, 1986). As a whole, flavor and overall palatability are not dramatically different over the 10 to 20% fat range. Costello et al. (1985) reported that flaked and formed beef steaks containing 15, 20, or 25% fat and cooked in a microwave oven were less tender, had less moisture release, seemed more well done, and had greater cooking losses than did broiled steaks. Further reductions in fat below 10% and retention of desirable palatability traits may be possible in restructured meats and sausages by the inclusion of less caloric dense ingredients such as fat reduced beef/pork, partially defatted chopped beef/pork, mechanically separated poultry/turkey (skinless), or non-meat ingredients that serve as partial fat replacements. Another fat replacement for whole-muscle products, such as precooked roast beef or boneless hams, is a high-protein meat slurry that is injected into the product in the same manner as a brine. Thus, the fat content is decreased with the addition of water and protein.

Prior to the 1980s, consumers generally preferred ground beef that contained 20 to 30% fat, and when the fat content dropped below 15%, it became less acceptable (Pearson et al., 1987). However, decreasing the fat content of ground beef patties to less than 10% simply by selecting leaner trimming sources often produces a product that is less flavorful, less juicy, and more cohesive. With an increased emphasis on decreasing total fat in the diet, additional ingredients are required to produce low-fat products that meet consumer expectations.

Tissues From Animals Fed Modified Diets

Dietary modifications of ruminant (beef) diets with forages and grain (Marmer et al., 1984; Miller et al., 1987), encapsulated linoleic acid ($C_{18:2}$) (Garrett et al., 1975), or rapeseed (60% oleic acid, $C_{18:1}$) (St. John et al., 1987) cause slight alterations of the fatty acid profile and fat content of edible tissues. These changes, however, are not of sufficient magnitude to effectively alter meat product composition. On the other hand, altering the lipid component of monogastric (pork) diets with additions of 10 to 20% safflower oil, high oleic acid sunflower oil, canola oil, or rapeseed significantly changes the fatty acid composition of both adipose and muscle tissues (St. John et al., 1986; Rhee et al., 1990; Shackelford et al., 1990c). This, in turn, alters the fatty acid composition of products manufactured from these tissues.

In studies by St. John et al. (1987), total saturated fatty acids in adipose and muscle tissues from pigs fed diets with 20% canola oil decreased from 40 to 15% and 42 to 23%, respectively, whereas monounsaturated/saturated ratios (M/S) increased from 1.19 to 3.63 and 1.21 to 2.46, respectively. For pigs fed a 10% canola oil diet, total saturated fatty acids and M/S ratios were intermediate between the previous values. Primal cuts from pigs receiving the 20% canola oil, however, were oilier and less firm, which would be detrimental to fresh product appearance and processing efficiency. Frankfurters (22% total fat) with a 60% pork meat block from pigs fed 10 and 20% canola oil (St. John et al., 1986) had 11.0 and 18.6% less saturated fatty acids, respectively (Table 8.2). Most sensory characteristics were similar except for a slight off-flavor in the 20% franks. In a similar study, M/S ratios of pork loin chops and eye of round roasts (Table 8.3) from pigs fed a diet with 12% high oleic acid sunflower oil were 49 and 66% higher, respectively, than the controls (Rhee et al., 1990). Cooking losses and sensory properties in this case were not affected adversely as a result of changes in fatty acid composition. Shackelford et al. (1990a,b,c,d) processed boneless hams, bacon, low-fat sausage, and fermented sausage from pigs fed diets containing 10% sunflower, safflower, or canola oil. The M/S ratios in most products ranged from 1.2 to 1.3 in controls to 1.9 to 2.5 in treated samples, and polyunsaturated fatty acids increased by about 7%. Products manufactured from 10% canola oil tissues scored lowest for flavor and palatability. As shown in the previous examples, monogastric animals incorporate fatty acids from the diet into tissues (i.e., oleic acid, a monounsaturated fatty acid), and these, in turn, alter the fatty acid composition of the finished product.

Alterations in the fatty acid composition and cholesterol content of emulsified meat products also can be achieved by direct addition of peanut oil or high oleic acid sunflower oil during the manufacturing process (Marquez et al., 1989; Park et al., 1989, 1990). Replacement of 30 to 60% of the fat with oil in low-fat frankfurters (12 to 15%) can increase the M/S ratio by 178 to 468% in comparison to a regular 30% fat frank with animal fat. Heat processing conditions, however, must be controlled more carefully to prevent loss of the oils with lower melting points.

Ingredient Additions and Substitutions

Processed meats, such as ground beef, coarse ground sausage, and emulsified meat products, are typically higher in fat content than are whole-muscle fresh cuts and cured products; bacon, however, which is higher in fat, may be an exception. Ground beef patties, Polish sausage, beef sausage, bologna, and frankfurters are examples of products that are allowed to contain up to 30% fat, and as much as 50% fat is allowed in fresh pork sausage. Because of the caloric density of these products, they are viewed as foods that contribute substantially to the fat calories in the diet when consumed on a regular basis. Processed products, however, have the greatest opportunity for fat decreases and/or modification because their composition can be altered by reformulation with a fat replacement.

Table 8.2. Fatty acid profiles of frankfurters (St. John et al., 1986)

	Fatty acid (%)							
Treatment content	$C_{16:0}$	$C_{16:1}$	$C_{18:0}$	$C_{18:1}$	$C_{18:2}$	$C_{18:3}$	Total saturated fatty acids	Total unsaturated fatty acids
By diet								
Control	23.7[a]	1.9[a]	11.0[a]	48.1[a]	12.5[b]	1.5[a]	34.8[a]	63.9[c]
10% CO[d]	18.0[b]	0.3[a]	6.2[b]	52.9[a]	17.5[a,b]	4.2[a]	24.2[b]	74.9[b]
20% CO	12.3[c]	0.7[a]	4.3[b]	54.3[a]	20.8[a]	6.7[a]	16.6[c]	82.5[a]
By fat content								
Regular (28%)	18.8[a]	1.5[a]	7.8[a]	50.6[a]	15.9[a]	4.2[a]	26.7[a]	72.2[a]
Lite (22%)	17.3[a]	0.6[a]	6.8[a]	52.7[a]	17.8[a]	4.0[a]	24.0[a]	75.1[a]

[a,b,c]Means with same letter in each column are not different ($P > 0.05$) when analyzed by diet or by fat content.
[d]CO = Canola oil.

Table 8.3. Fatty acid profiles of cooked *longissimus dorsi* chops and *semitendinosus* roasts (Rhee et al., 1990)

	Longissimus dorsi				*Semitendinosus*			
	Cooked[1]		Raw[1]		Cooked[1]		Raw[1]	
	Control diet (%)[3]	HOSO[2] (%)[3]	Control diet (%)[3]	HOSO[2] (%)[3]	Control diet (%)[3]	HOSO[2,3] (%)[3]	Control diet (%)[3]	HOSO[2] (%)[3]
Fatty acid								
$C_{14:0}$	0.69[a]	0.71[a]	0.71[a]	0.74[a]	0.97[a]	0.79[a]	0.99[a]	0.91[b]
$C_{16:0}$	23.05[a]	19.48[a]	23.81[a]	19.59[b]	26.29[a]	20.64[b]	24.32[a]	18.59[b]
$C_{16:1}$	1.96[a]	1.41[a]	1.94[a]	1.35[b]	2.56[a]	1.85[b]	2.60[a]	2.25[b]
$C_{18:0}$	12.11[a]	8.94[b]	13.14[a]	9.35[b]	14.02[a]	10.39[b]	12.75[a]	9.02[b]
$C_{18:1}$	44.03[b]	53.14[a]	41.94[b]	52.72[a]	38.15[b]	49.51[a]	39.20[b]	49.95[a]
$C_{18:2}$	14.61[a]	13.66[a]	14.14[a]	12.72[a]	14.28[a]	13.14[a]	15.12[a]	14.66[a]
$C_{20:1}$	0.32[a]	0.45[a]	0.52[a]	0.62[a]	0.61[a]	0.99[a]	0.53[a]	0.62[a]
$C_{20:4}$	3.22[a]	2.22[a]	3.81[a]	2.92[b]	2.87[a]	2.70[a]	4.23[a]	4.01[a]
Total saturated	35.86[a]	29.13[b]	37.65[a]	29.68[b]	41.28[a]	31.82[b]	38.06[a]	28.51[b]
Total unsaturated	64.14[b]	70.87[a]	62.35[b]	70.32[a]	58.47[b]	68.17[a]	61.69[b]	71.48[a]
Total monounsaturated	46.31[b]	55.00[a]	44.40[b]	54.69[a]	41.32[b]	52.34[a]	42.33[b]	52.82[a]
Total polyunsaturated	17.83[a]	15.88[a]	17.96[a]	15.64[b]	17.15[a]	15.84[a]	19.36[a]	18.66[a]
Ratio								
Unsaturated/saturated	1.80[b]	2.52[a]	1.67[b]	2.41[a]	1.42[b]	2.17[a]	1.62[b]	2.52[a]
Monounsaturated/saturated	1.30[b]	1.94[a]	1.19[b]	1.88[a]	1.00[b]	1.66[a]	1.11[b]	1.86[a]
Polyunsaturated/saturated	0.51[a]	0.57[a]	0.48[a]	0.54[a]	0.41[a]	0.50[a]	0.51[b]	0.65[a]

[1]Means in the same row within each cooking state category (cooked or raw) with the same superscript letter are not different ($P>0.05$).
[2]HOSO: high-oleic sunflower oil.
[3]Area percent.

Fat replacements or substitutes are ingredients that contribute fewer or no calories to formulated foods without altering flavor, mouthfeel, viscosity, or other organoleptic properties. Most are used for partial rather than total replacement of the fat and are categorized as (1) added water, (2) protein-based (soy, milk, whey, egg, wheat, oat, corn) flours, concentrates, or isolates, (3) starches, hydrocolloids (gums), maltodextrins, or dextrins, and (4) new generation synthetic compounds (Tables 8.4, 8.5, and 8.6). Proteins and some gum replacements bind water and meat in the meat-gel matrix, whereas starches, dextrins, and maltodextrins primarily bind water.

Added Water

Decreasing the fat content by substitution of a portion of the fat with lean increases the overall cost of a meat item, and, for ground beef or sausages, can result in a less flavorful, dry, tough, and rubbery product. Frankfurters and bologna are allowed to contain combinations of fat and added water not to exceed 40% with a maximal fat content of 30%. This allows, for example, a 10% fat frankfurter to be produced with 30% added water; water replaces two-thirds of the fat. Substitution of large amounts of fat with water alone, however, may not give the optimal sensory and textural properties that consumers are accustomed to or desire. Claus et al. (1989) processed bologna formulations ranging from 30% fat/10% added water (control) to 5% fat/35% added water and found the lowest fat, highest added water bologna to be less firm, more cohesive, juicier, and darker but with greater cooking and purge losses. Regression analyses, however, revealed that bologna with 10% fat required 24.3% added water to approximate the sensory firmness of bologna with 30% fat/10% added water. In a study by Park et al. (1990), consumers indicated that low-fat (14 to 16% fat) frankfurters with about 24% added water were as acceptable as 28% fat controls. Thus, substitution of fat with added water in sausage products decreases caloric density but can alter the physical, sensory, and textural characteristics of low-fat products.

Protein Substitutes

Protein additives used in meat products include wheat flour, vital wheat gluten, soy flour, soy protein concentrate, soy protein isolate, textured soy protein, cottonseed flour, oat flour, corn germ meal, nonfat dry milk, calcium-reduced nonfat dry milk, caseinates, whey proteins, surimi, blood plasma, and egg proteins (Table 8.4). Singly or collectively, most protein

Table 8.4. Potential protein-based fat replacements for processed meats (Keeton, 1991)

Fat replacement (source)	Calories/g (dry weight)	Comments
Soy flour/textured soy (~50% protein)	4	Used at 3.5% level; if higher, loss of Standard of Identity. Binder/extender, rehydrate at 3 parts water to 1 part protein. Ground meat products.
Soy concentrate (~70% protein)	4	Same as above.
Soy isolate/textured isolate (90% protein)	4	Used at 2.0% level; if higher, loss of Standard of Identity. Binder/extender, rehydrate at 5 parts water 1 part protein. Bland flavor. Can form gel. Coarse and fine ground products. Patties and nuggets.
Wheat gluten (70% protein)	4	Used at 3.5% level; if higher, loss of Standard of Identity. Binder/extender, mix dry then add 3 parts water to 1 part protein. Forms elastic gel when heated above 185ºF in canned meats.
Calcium-reduced dried skim milk (Ca lactate at 10% of binder) (35% protein)	4	Used at 3.5% level; if higher, loss of Standard of Identity. Some water binding, produces lower tensile strength. May need to increase spicing levels.
Whey protein (19 to 33% protein)	4	Same as above.
Whey protein concentrate (~75% protein)	4	Used at 3.5% level; if higher, loss of Standard of Identity. Restructured meats primarily.
Sodium or calcium caseinate Milk hydrolysate (~90% protein)	4	Used at 2.0% level; if higher, loss of Standard of Identity. Enhances water retention (rehydrate at 5 parts water 1 part caseinate) or used in fat preemulsions (8:8:1 fat:water:caseinate). Sausage, emulsion-type products, restructured meats, coarse chopped sausages.

ingredients included as fat replacements in cooked sausages are allowed at concentrations up to 3.5% on a dry-weight basis, but soy protein isolates or caseinates (~90% protein) are restricted to 2%. If these concentrations are exceeded in products that have a Standard of Identity (i.e., frankfurters), then the product must bear a name other than the standardized name. Overextension of low-fat meat products with protein additives can be detrimental to sensory characteristics.

Protein binders/extenders traditionally have been used most in ground beef patties, meat patties, pepperoni, pizza toppings, low-cost sausages, and other formed meats. Ground beef patties formulated to contain 0, 15, 20, and 25% textured soy protein (TSP) and 15, 20, 25, and 30% fat had less cooking loss with increased amounts of TSP; patties, however, had less beef flavor with increasing amounts of TSP (Drake et al., 1975). Berry et al. (1985a) found beef patties adjusted to 22% fat and extended with 20% rehydrated soy isolate to be more similar in texture to all-beef patties and to have less soy flavor than those patties with soy flours or concentrates. Acceptable frankfurter-type products ranging from 12 to 20% fat can be produced with 45 to 50% lean, 5 to 30% proportions of hydrated (1:4) soy protein isolate, or 25 to 30% hydrated (1:2) textured soy protein (Sofos and Allen, 1977). Likewise, 3.5% vital wheat gluten or soy protein concentrate also may serve as acceptable fat replacements in frankfurters or Vienna sausages (12% fat) formulated to contain 28% added water (Gilchrist, 1987). Other low-fat (10%) emulsified sausages have been manufactured by using milk protein hydrolyzates and calcium or sodium caseinates to preemulsify liquified fat (or oil) and stabilize the meat batter during cooking (Hoogenkamp, 1989). Jeng et al. (1988) suggested that tofu has the potential of being a fat substitute in bologna (12% fat) when used at 31.6% of the meat block.

Most carbohydrates that are available for use as fat substitutes are gums (hydrocolloids), starches, fibers, or cellulose-based derivatives (Table 8.5). Foegeding and Ramsey (1986) reported kappa and iota carrageenan at <1% of the raw batter weight to be the most beneficial gums for manufacturing low-fat (11 to 12%), high moisture frankfurters. Lin et al. (1988), on the other hand, concluded that 0.25% carboxymethylcellulose caused frankfurters containing 14 to 15% fat to be less rubbery. In another application, Huffman and Egbert (1990) incorporated 0.5% carrageenan, 0.375% encapsulated salt, 0.188% hydrolyzed vegetable protein, and 3.0% water into low-fat (9%) beef patties (Figure 8.1). The carrageenan treatment in the 9%

Table 8.5. Potential carbohydrate based fat replacements for processed meats (Keeton, 1991)

Fat replacement (source)	Calories/g (dry weight)	Comments
Gums or Hydrocolloids		
Carrageenan, kappa and iota (seaweed)	<1	Used alone at 0.3 to 0.7% levels and/or in combination with starches, soy protein isolate, sodium caseinate, and other ingredients. Up to 1% allowed in meat products. Gelcarin®, Viscarin®.
Konjac flour (amorphophallus tuber)	<1	Has 65% fiber (polysaccharide) with a mouthfeel similar to shortening or fat. Possible use in coarse ground meat products (hamburger or sausages) or precooked items. Synergistic with kappa carrageenan and starch. Standardized with 8 to 12% dextrose. Nutricol®.
Alginate, sodium, or calcium	<1	Use at ≤1 in conjunction with Ca carbonate (0.2%), lactic acid/Ca lactate (or glucono delta lactone) not to exceed 0.3%. Added mixture cannot exceed 1.5% of formulation. Restructured meats.
Locust bean gum	<1	Possible use in coarse and emulsion sausages in combination with kappa carrageenan at ≤1%. Compatible with all gums.
Starches		
Corn starch maltodextrin	4	Use up to 3.5% singly or in combination with binders; if higher, loss of Standard of Identity. Suggested for sausages. Has a DE of 5. DE is a measure of reducing sugar content calculated as % dextrose. DE of dextrose = 100, whereas DE of starch = 0. Maltrin® M040.
Modified waxy maize	4	Same as above. Firm-Tex®.
Tapicoa dextrins and maltodextrins	4	Same as above. N-Oil®, pregelatinized.
Potato starch maltodextrin	4	Same as above. DE of <5. Paselli SA2.
Modified potato starch	4	Same as above. Sta-Slim™ 143.
Oat fiber	4	Same as above. Better Basics™ #770.
Rice flour	4	Same as above.
Cellulose derivatives		
Microcrystalline cellulose	<1	Use level of ~3.5% in ground meat patties. Solka-Floc®, Avicel®.
Methylcellulose Carboxymethylcellulose	<1	Use level varies from 0.25-1.0%; may be combined with gums. Methocel®.

Table 8.6. Potential synthetic compounds for fat replacement in processed meats (Keeton, 1991)

Fat replacement (source)	Kcal/g (dry weight)	Comments
Polydextrose	1	~1.0% use level as a partial fat substitute. Protects proteins from denaturation and water loss upon thawing. Possible use in brines and meat emulsions.
Olestra (sucrose polyester)	0	Experimental, pending FDA approval. Procter & Gamble Co. High temperature oil or shortening substitute.
EPG (esterified propoxylated glycerols)	0	Experimental. ARCO Chemical Co. Fat and oil substitute with a structure similar to natural fat. Resistant to enzymatic hydrolysis.
DDM (dialkyl dihexadecymalonate)	0	Experimental. Frito-Lay, Inc. High temperature oil substitute. Minimally digested.
TATCA (trialkoxytricarballate)	0	Experimental. Best Foods. Oil substitute and possible resistance to hydrolysis by digestive enzymes.

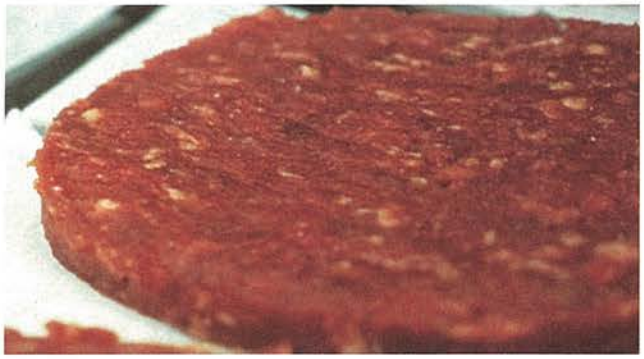


Figure 8.1. **Scientists at Auburn University in Alabama have developed a low-fat version of ground beef. AU lean has half the fat and 40% fewer calories than conventional hamburger. Photograph courtesy of National Live Stock and Meat Board.**

fat (raw) pattie was equal in sensory acceptability and beef flavor to a 20% fat pattie and decreased the caloric density by 55 to 60 kcal/100 g serving or a caloric decrease of 22 to 23% on an as-eaten basis (Table 8.7). As a result of this research, the McLean beef patty (9% fat) with carrageenan was introduced by McDonalds in 1991 and has resulted in several types of reduced-fat beef patties being developed for fast-food and retail distribution. These scientists also have developed low-fat sausage that uses carrageenan and other seasonings to decrease fat content to 12.5%. Store brand sausages may average from 30 to 43% fat and, with introduction of a low-fat sausage, a decrease of 60 to 70% fat and over half the calories could be achieved in comparison to traditional pork sausage.

Carbohydrate Substitutes

Starches have been used in the meat industry to improve cooking yields (as a result of their ability to absorb large amounts of water), enhance juiciness, decrease formulation costs, and serve as cryoprotectants in frozen surimi products, but they also offer potential for fat replacement. Odio (1989) concluded that modified waxy maize starch, rice flour, and tapioca dextrin, when used at 2.5 to 5% of the formulation, were potential fat substitutes for frankfurters having 9 to 15% fat. Additional starches, such as pregelatinized potato starch, potato flour, and oat fiber, are also potential fat replacements in beef patties and coarse sausages having 5 to 15% fat content.

Noncaloric synthetic fat substitutes (Table 8.6) such as sucrose polyester are not currently approved for use by the FDA, but this new class of food ingredients may offer potential as fat replacements in meat products because of their ability to mimic the texture and function of fat.

New Process Technologies

Inter- and intramuscular fat and cholesterol in whole muscle tissue are essentially fixed unless methods can be developed to separate these components without dramatically altering the compositional or textural characteristics of the tissues. Technology is becoming available to possibly segregate these components from intact tissues and recover usable meat from ground or emulsified raw materials.

Surimi is a wet, frozen concentrate of myofibrillar proteins from fish muscle that is usually prepared by fresh water washing of mechanically deboned fish muscle followed by the addition of ingredients to prevent protein denaturation during freezing. This process also may have application in converting lean meat trimmings or mechanically separated meats into a highly functional and nutritious ingredient. Finely ground or emulsified meats could be washed to remove lipid components, centrifuged to extract excess water,

Table 8.7. **Proximate analysis and energy content of cooked ground beef patties (Huffman and Egbert, 1990)**

	Proximate analysis[2] (%) and energy content (kcal/100 g)				
Treatment[1]	Water	Fat	Protein	Ash	Energy
1	56.3^{b}	18.7^{c}	21.7^{d}	1.27^{b}	255^{c}
2	63.4^{c}	10.8^{b}	25.4^{b}	1.14^{b}	199^{b}
3	63.2^{c}	10.9^{b}	24.5^{bc}	1.25^{b}	196^{b}
4	62.5^{c}	11.4^{b}	24.1^{c}	1.29^{b}	199^{b}

[1]Treatments are (1) 20% fat product (control) ground through a 1/8-in. (0.32-cm) grinder plate, (2) 10% fat product ground through a 1/8-in. plate, (3) 10% fat product with 0.25% salt and 0.125% hydrolyzed vegetable protein (HVP) added, ground through a 3/16-in. (0.48-cm) grinder plate, and (4) 10% fat product with 3% water, 0.375% salt, 0.188% HVP, and 0.50% carrageenan added, ground through a 3/16-in. grinder plate.
[2]Means within a column with different superscripts are significantly different ($P<0.05$).

mixed with low amounts of salt, sodium tripolyphosphate, and sucrose/sorbitol, and frozen for later use. Some water-soluble nutrients that might be lost during the washing process could be recovered through a second centrifugation process.

"Naturalean," a process developed by Chapman Meats (Australia) Ltd., claims to separate fat and cholesterol from conventionally deboned, trimmed lean by a process that finely minces the meat tissues in a high speed chopper, followed by the addition of a small amount of vinegar to decrease the pH and aggregate the proteins; then, the fat is solidified on a cold surface heat exchanger (Anonymous, 1988). The lean component then can be removed from the surface of the fat and used for producing patties, sausages, emulsion products, meat fillings, or toppings.

Another potential method for removing fat and cholesterol from meat is that of supercritical fluid extraction with carbon dioxide (SCO_2). Finely minced or dehydrated meats and/or fish are exposed to pressures from 2,000 to 5,000 lb/in.^{2} × g (psig) at a temperature of 40° to 50°C for three or more hours. Hardardottir and Kinsella (1988) found that SCO_2 and SCO_2 with ethanol removed 78 and 97% of the lipids and 97 and 99% of the cholesterol, respectively, from trout muscle. They also noted that the solubility of muscle proteins decreased following extraction, which might pose problems with subsequent use in processed products. The SCO_2 of dehydrated beef or chicken powders has been demonstrated to remove over 85% of total lipid and cholesterol, but removal of these components from dehydrated chicken meat chunks is slightly less efficient. A problem that remains to be resolved, however, is to determine if lipid rancidity increases in products after the extraction process.

A decrease of cholesterol in meat products in the future may be possible through the conversion of cholesterol to coprostanol, which is not absorbed readily in the intestine. Dehal et al. (1989) isolated cholesterol reductase from alfalfa leaves, and Beitz (1990) reported that cucumbers and human fecal cultures may be an additional source of the enzyme. Treatment of meat animals might involve an injection of the enzyme immediately prior to slaughter, allowing for the conversion of a portion of the membrane-bound cholesterol into a relatively inert compound. Further characterization of the enzyme and development of this technology is currently underway to determine its potential application in a variety of animal-derived foods.

Low-calorie and noncaloric fat replacements that have similar textural characteristics to fat possibly could serve as functional ingredients in some low-fat processed meat products. Examples of these are sucrose polyester or olestra (Procter and Gamble), polyglycerol esters, and Polydextrose® (Pfizer, Inc.). Starches (potato, corn) and hydrocolloids (algins) may serve as fat replacements by holding additional water, decreasing caloric content, and diluting total cholesterol in a meat product.

Fish Products

Cultured fish are fed prepared diets containing soybean meal in which omega-6 fatty acids are the dominant fat source, whereas cold water marine fish consume primarily phytoplankton that is rich in omega-3 fatty acids. These dietary differences affect the fatty acid composition of fish species which, in turn, influence the type of fat in the human diet. Pond-reared catfish and shellfish contain fewer omega-3 fatty acids than found in cold water seafood (Hearn et al., 1987), but dietary manipulation can elevate this nutrient. Catfish diets with 3% menhaden oil increase the concentrations of docosapentaenoic acid (22:5) and docosahexaenoic acid (22:6) by 57 and 45%, respectively, without significantly changing sensory properties (Hayes, 1989). However, the total percent fat of the fillets also increases proportionally with the percent fat in the diet.

The method of cookery affects the final fat content and fatty acid composition of fish foods. Frying farm-raised catfish fillets increases the total fat content by 1.6% when compared with baking, and the fatty acid profile of the fried fillets is significantly altered by the uptake of linoleic acid ($C_{18:2}$) from the frying oil (Mustafa and Medeiros, 1985). Makinson et al. (1987) also found an increase in the fat content of deep-fat fried fish and noted that batters, but not breadings, retarded fat migration into the fish. Microwave cookery of lean fish, such as grouper, results in lower amounts of $C_{22:6}$ and higher amounts of $C_{16:0}$, $C_{22:0}$, and $C_{20:2}$, but no differences in fatty acid composition are noted for red snapper, pompano, and Spanish mackerel, which are of medium to high fat content (Gall et al., 1983).

Processing and Ingredient Additions and Substitutions

Minced blends of different fish species or combinations of minced fish with other meats effectively decrease fat content and offer potential for the development of new forms of fish products. Rockower et al. (1983) found that minced patties containing <10% fat and 78% turbot, 11% soy flour, and 11% soy protein concentrate were the most acceptable when compared with other combinations of pollack, turbot, and soy proteins. Other products, such as a catfish sausage ball (Medeiros et al., 1986) with 10% less fat than a pork ball, might offer a nutritional advantage in terms of a decrease in calories and modification of the fatty acid composition, but "fishy" flavors typically limit the development of mixed species products. Frankfurter analogs containing 10% Pacific hake or as much as 100% red hake surimi have less fat and are similar in appearance to the more traditional sausages but often do not achieve the same degree of acceptance of products containing beef (Buck and Fafard, 1985; Park et al., 1978). However, with reformulation and further development of fish analogs, prepared fish products offer great potential for low-fat foods with desirable fatty acid profiles.

Surimi

Surimi is a low-fat, frozen concentrate of myofibrillar proteins from fish muscle, which typically contains salt, sodium tripolyphosphate, and a blend of sucrose/sorbitol and can be processed into a variety of fish/seafood analogs (Lanier, 1986; Lanier et al., 1988; Lee, 1986). An imitation crab analog manufactured from surimi might contain 74.5% water, 12.0% protein, 10.25% carbohydrates, 1.3% fat, 841 mg sodium/100 g, 20 mg cholesterol/100 g, and have 100 kcal/100 g portion. Raw surimi is a basic building block for a variety of seafood items because of its ability to form a gelled protein matrix, entrapping several ingredients and allowing the formation of a variety of textures, tastes, and shapes in a food product. Future research likely will yield other uses for fish-based analogs and possible development of a low-fat, washed, minced tissue from red meat species.

9 Altering Fat Composition of Poultry and Egg Products through Production and Processing

Summary

Poultry have white meat in greatest proportion. White meat is low in fat because intermuscular depots are few, whereas dark meat is similar to the red meats. Body lipids are low in the saturated fatty acids because of the nature of intestinal fat absorption and liver metabolism. Polyunsaturated fatty acid content of meat is largely a function of content of those acids in feed. Depot fat increases with age and is greater in females than males. Deposition can be discouraged by management practices that limit energy intake and using feed that is balanced to favor protein deposition. Skin represents the largest depot of body fat. Movement of fat from skin into meat during cooking is small. Thus, fat consumption can be minimized by avoiding skin. Coatings on the parts during preparation and gravies made from drip loss are expected to be high in fat. Fat content of further processed products usually depends on meat source and if skin is included.

Eggs have all the fat contributed by yolk. Cholesterol is in association with other lipids, and their total represents one-third of the yolk dry matter. Yolk lipoproteins are formed in the liver as a response to estrogen and then transported to the ovary. Whereas the amount of yolk can change with genetics, age, and nutrition of the hen, concentration of lipids in yolk is reasonably constant. Practical efforts at decreasing cholesterol have had minimal response. As with meat, saturated fatty acids are low, whereas the polyunsaturated ones vary with their content in feed. Lipids in processed eggs follow their contribution to the final product, but concentrations may change if a portion of yolk has been omitted or substituted.

Meat

Meat-type fowl normally receive high performance feed that contains added fat. Fowl absorb fat and transport most of it as very-low-density lipoproteins (VLDLs) from the intestine directly to the liver. The liver is the primary site of all aspects of lipogenesis in fowl. Not only can the short- and medium-chained fatty acids be elongated, but the greatest proportion of saturated fatty acids are desaturated, particularly stearic acid, which is converted to oleic acid. In turn, fowl contain low concentrations of saturated fatty acids, regardless of dietary content. The dietary polyunsaturated fatty acids are not altered to any degree, and thus body lipids reflect those in the feed.

Depot fat cells in fowl are almost exclusively storage areas for fat. These cells accept the fatty acids transported there as VLDLs from the intestine and liver. High proportions of the polyunsaturated fatty acids in depot lipids are possible when they are in the feed. While such alterations may be nutritionally favorable to the consumer at "moderate" levels, "high" levels, such as could arise from fish oils, could lead to problems. For example, increasing the extent of unsaturation greatly increases susceptibility to peroxidation. This deterioration can be avoided by dietary antioxidants, particularly vitamin E, while the bird is alive; inadequate vitamin E, extended storage, and cooking, however, accentuate the appearance of byproducts to create "fishy" flavors.

Fat Depots

Fat is stored in three distinct areas of the body. The intestinal system and lower abdominal cavity have depots that envelope most of the associated organs. Evisceration of the bird during processing removes most of this fat; however, some remnants in the body cavity may remain. Skin represents the largest depot with the "ready-to-cook" carcass. Fat cells tend to localize at areas where feathers had been attached, particularly with the breast and pelvic back. Thigh meat has an extensive network of depots between the various muscles.

The amount of body fat increases with age; the rate of increase, however, is not uniform among the depots. Abdominal fat has the most rapid rate of increase during juvenile development. Depots in the skin and thigh follow and exhibit rapid accrual with the initiation of sexual maturation. Differences between the genders in body fat are accentuated at this time. Estrogen expands the capacity of liver for lipogenesis and the ability of adipose tissue to accept fatty acids, whereas the androgens are considerably less influential.

Several commercial strains of chickens and turkeys are available for meat production. Differences frequently appear among the strains for each species in body weight and depot fat. Alterations can be attributed largely to the nature of selection and age when measurements were taken. Selection for body weight when young generally favors early maturation, whereas the converse occurs when measurements are taken at more mature ages. Presently, body fat is viewed as an important consumer item, and selection pressure to decrease it is being imposed.

Live Production

A decrease in the amount of body fat is possible through flock management. For example, limiting energy intake either directly through feed access or indirectly by lighting has been successful, but this management technique requires experienced caretakers. Changing composition of diet also can be employed. For example, formulating feed such that (1) protein is high relative to total energy content, (2) amino acids are in balance with needs, and (3) carbohydrate preferentially provides the energy all discourage fat deposition.

Management and nutrition are of particular benefit concurrent to onsetting of sexual maturation. Not only is fat rapidly accruing at this time, but the skin and thigh meat depots are most sensitive. Furthermore, these tissues are most important to the consumer in terms of fat in poultry as a food.

Consumer Practices

Breast and thigh provide the overwhelming proportion of meat from the carcass. Breast meat is particularly low in fat, as these muscles do not readily use fatty acids as a source of energy and associated depots are minimal. On the other hand, thigh muscles can oxidize fatty acids readily, and the intermuscular depots are located in the immediate area as found in red meats. Alterations in body fat because of age, gender, strain, management, and nutrition are exhibited by thigh meat; breast meat, however, is refractory.

Cooking alters meat composition (Table 9.1). Conductive (oven and frying), convective (moving hot air), and microwave (water friction in meat) procedures usually require different cooking times to attain any one

Table 9.1. Lipid composition of roasted broiler chicken and turkey (100 g portion) (National Live Stock and Meat Board, 1988)

	Chicken				Turkey			
	White meat		Dark meat		White meat		Dark meat	
	With skin	Without skin	With skin	Without skin	With skin	Without skin	With skin	Without skin
Total fat (g)	7.78	3.57	13.46	8.43	8.33	3.22	11.54	7.22
Cholesterol (mg)	84.00	85.00	92.00	94.00	76.00	69.00	89.00	85.00
Energy (kcal)	197.00	165.00	232.00	191.00	197.00	157.00	221.00	187.00
Fatty acids								
Saturated, total (g)	2.19	1.01	3.72	2.29	2.34	1.03	3.49	2.42
C_{12}	0.01	0.01	0.03	0.03	0.01	0.01	0.01	0.02
C_{14}	0.06	0.03	0.10	0.06	0.06	0.02	0.08	0.05
C_{16}	1.61	0.69	2.71	1.59	1.45	0.47	2.10	1.28
C_{18}	0.45	0.25	0.77	0.54	0.55	0.31	0.90	0.72
Monounsaturated, total (g)	3.03	1.24	5.24	3.05	2.84	0.56	3.65	1.64
$C_{16:1}$	0.40	0.15	0.73	0.42	0.47	0.07	0.59	0.24
$C_{18:1}$	2.51	1.04	4.32	2.54	2.29	0.46	2.97	1.35
Polyunsaturated, total (g)	1.66	0.77	3.00	1.97	2.01	0.86	3.09	2.16
$C_{18:2}$	1.41	0.59	2.59	1.62	1.64	0.57	2.61	1.75
$C_{18:3}$	0.06	0.03	0.12	0.08	0.10	0.01	0.14	0.07
$C_{20:4}$	0.07	0.06	0.12	0.13	0.16	0.17	0.24	0.26
Fatty acids as % of total fat								
Saturated	28.15	28.29	27.64	27.16	28.09	31.99	30.24	33.52
Monounsaturated	38.95	34.73	38.93	36.18	34.09	17.39	31.63	22.71
Polyunsaturated	21.34	21.57	22.29	23.37	24.13	26.71	26.78	29.92

internal temperature. Losses from the meat occur because of denaturation to cellular protein that decrease the moisture holding capacity, and fat is rendered from depot areas. The extent of these losses differ among the cooking procedures, but the resulting alterations to meat composition are similar.

Total fat in the drip largely relates to the amount of fat in the skin. Fat in the meat increases in concentration more because moisture has been lost than can be attributed to gain from adjacent depots. Skin is the largest fat depot adjacent to meat, and it may be separated readily after cooking to minimize fat intake.

Fat has been credited with improving the sensory characteristics of meat. Skin fat is believed to impede evaporative loss and maintain moisture in the meat, whereas intermuscular depots contribute flavor components directly. Because the skin and intermuscular depots largely appear at the end of live production, they have been referred to collectively as "finish." In turn, a minimal amount of finish is being used to assess quality as part of the governmental grading system. A poor correlation has been shown to exist between finish and eating quality. Improved eating quality also occurs with age, particularly during sexual maturation. Sex steroids not only increase fat deposition but alter muscle metabolism concurrently. Fat is but one factor in sensory quality.

Commercial Products

Convenience foods, deli, and specialty products are the primary reasons for the increased consumption of poultry. These foods represent varying degrees of processing beyond the ready-to-cook carcass. Furthermore, alteration in fat content can be manipulated substantially.

Fast foods are usually deep-fat fried; however, their meat is no higher in fat content than are meats after other means of preparation. "Deep basting" procedures that inject fat into meat have been shown to improve eating quality, particularly in relieving the "dryness" of breast meat. However, fat retained increases to a level similar to that of thigh meat, and the associated fatty acids in the basted meat now reflect those injected. Flour-based coatings used in conjunction with deep-fat frying and gravies produced from drip after roasting can be expected to contain substantial fat, which can have a multitude of origins.

Specialty roasts, cold cuts, and precooked entreés are examples where meat has been removed from the carcass and converted into a convenient form. Fat content is altered by the selective use of muscle, skin, and mechanically deboned meat (MDM). Specialty roasts may have the breast skin wrapping the dark and/or white meat either in ready-to-cook or precooked form. Breast meat alone may be used to manufacture simulated pastrami; thigh meat may be used to make ham-like products.

The MDM is the pureé resulting when residual carcass parts are pressurized such that the "soft" tissues separate from the bone. Soft tissues represent skin, meat, and collagens with their proportions being dependent on the carcass parts used. Necks and backs commonly are used, and skin, when included, may greatly increase the fat content. The MDM may be used in casings with large pieces of meat to fill voids and act as a binder or may be used as the basis of bologna, salami, sausage, and frankfurters. Possible alterations in fat content and fatty acid proportions are extensive; however, the level chosen is a minimal one and necessary to optimize sensory quality.

Eggs

The yolk approximates 25% of the egg volume and contains all of the cholesterol and other lipids (Table 9.2). Total lipid occupies one-third of the yolk, which originates from two types of lipoproteins. Each lipoprotein is the basis for two aggregates in the yolk. The

Table 9.2. Food energy, protein, and lipid contents of eggs (per 100 g edible fluid raw product) (Naber, 1979)

	Whole egg	Albumen	Yolk
Total fat (g)	15.00	Nil	33.00
Cholesterol (mg)	600.00	—	1323.00
Energy (kcal)	163.00	47.0	362.00
Protein (g)	12.60	10.4	16.20
Fatty acids			
Saturated	5.80		11.40
C_{12}	0.60		0.13
C_{14}	0.40		0.15
C_{16}	3.00		8.00
C_{18}	0.97		2.50
Monounsaturated (g)	5.50		14.80
$C_{16:1}$	0.47		2.50
$C_{18:1}$	4.90		13.20
Polyunsaturated (g)	3.10		5.20
$C_{18:2}$	1.60		4.10
$C_{18:3}$	0.30		0.70
$C_{18:4}$	0.80		0.29
Fatty acids as % of total fat			
Saturated	38.70		34.50
Monounsaturated	36.70		44.80
Polyunsaturated	20.70		15.80

smaller aggregate is high in lipids, whereas the other is dominated by protein having extensive phosphorus. Both are assembled in the liver where cholesterol is incorporated and then transported to the ovary. Yolk lipoproteins only can occur when estrogen is present.

Liver cells also synthesize bile acids from cholesterol. The bile acids aggregate together with cholesterol and phospholipid to yield distinct lipid micelles in bile. Bile micelles are necessary for the effective recovery of dietary fat from the intestine. Bile micelles and yolk lipoproteins are continuously formed by the hen. Thus, some competition for mutual components can be expected. Providing cholesterol, phospholipids, fat, and bile in the feed relieves the necessity of their synthesis and permits maximal formation of bile and yolk.

Altering Yolk

The concentration of solids in yolk is reasonably constant, but the amount of yolk produced with each egg may change. Total yolk increases with hen age and size of the egg. The extent of these alterations is influenced by strain of bird and her nutrition during egg formation. Whereas hens are capable of laying an egg a day, any one yolk represents an accrual through the preceding seven days.

Adding fat to feed generally increases the amount of yolk and egg size, particularly with young hens having a rapid rate of lay. Polyunsaturated fatty acids are more effective in this respect than are saturated ones. As with meat, saturated fatty acids do not appear in the egg at high concentrations because of their hepatic conversion to monounsaturated fatty acids. Dietary polyunsaturated fatty acids are transferred readily to yolk lipids, with the extent being related largely to their consumption.

Concentration of cholesterol in the yolk can be increased, but not substantially decreased. Adding cholesterol to the feed increases that in the yolk, particularly when accompanied by polyunsaturated fat. Cholesterol does not occur in feed to any large extent, nor are polyunsaturated fatty acids present in extensive amounts under most conditions. Thus, eggs can be expected to have a minimal and relatively constant concentration of cholesterol. A decrease in cholesterol concentration is attainable by using feed ingredients high in soluble fiber to interfere with bile acid recovery and fat absorption, but such decreases are marginal (5 to 10%). Lipids in the yolk were intended to support embryonic development, and the hen will cease egg production before permitting cholesterol to fall below a lower limit.

Processed Eggs

Eggs may be processed into many commercially available products. These products may be categorized into three groups. The first group involves products immediate to separation from the shell, such as liquid, frozen, and dried albumen, yolk, and whole eggs. The second group converts these primary products into forms where eggs are not recognizable (e.g., baked goods, mayonnaise, and ice cream). Convenience (e.g., prehard-boiled eggs) and value-added products (e.g., prepared frozen omelets) represent the last group.

The cholesterol and lipid contribution from eggs into any product can be altered by simply removing all or a portion of the yolk. In some cases, yolk is substituted by other lipid composites. More sophisticated approaches involve selective extraction of cholesterol and leaving the remaining lipids that may perform important functional roles. This technology is in the beginning stages of development.

10 Manipulation of Edible Vegetable Oil Composition by Genetic Methods

Summary

Since the turn of the century, vegetable oils have supplanted lard and beef tallow as the major source of dietary fat. Today, the economic value of vegetable oils traded on the world market is estimated to be about $26 billion. A wide range of oilseed crops contribute to the world supply of edible vegetable oils. The major oilseeds are soybean, palm, sunflower, rapeseed (canola), cottonseed, peanut, coconut, olive, and palm kernel. Each of these edible vegetable oils have different physical/chemical attributes that are associated with fatty acid composition. These characteristics may be altered by chemical treatment, such as hydrogenation, to render properties that improve the oxidative stability of the oils or expand utilization of the oils in food products that require solid fats. The increased concentration of dietary saturated fat, the cost of oil processing, and environmental pollution resulting from chemical refining, however, have become major concerns of both consumers and producers of food products. These concerns promulgate the need for alternative approaches for altering fatty acid composition of vegetable oils for specific industrial applications. The most cost effective alternative is genetic modification of oil composition through plant breeding. This approach has been demonstrated successfully in many of the major oilseed crops, most prominently in rapeseed, safflower, and soybean. It is now possible to manipulate the proportions of each of the main fatty acid constituents of these oils to a desired concentration. Such efforts not only create natural vegetable oils with improved oxidative stability but also open new avenues to expand vegetable oil utilization. Because of the high degree of economic competition among oilseeds on the world market, crops that lack flexibility in adapting to changing industrial and public demands will most certainly lose market share in this multibillion dollar commodity. Altering fatty acid composition through plant breeding has shown significant potential for creating that flexibility. As basic knowledge of the biochemical and genetic regulation of oil composition grows to higher levels, new technologies will result with even broader applications. These events will become reality in the near future.

Introduction

Soybean, palm, sunflower, rapeseed (canola), cottonseed, peanut, coconut, olive, and palm kernel are recognized as the major oilseed crops that supply the bulk of the world's edible vegetable oils. Total oil production from these oilseeds in 1988 to 1989 is estimated to be 59.75 million metric tons (MMT). Of that total, 53.09 MMT is expected to be consumed, leaving a surplus of 6.41 MMT (Table 10.1). Four of these commodities (soybean, palm, sunflower, and canola) accounted for 76% of world edible vegetable oil production and for over 75% of total oil consumption in 1988 to 1989. Because of ample supply, these four oilseeds have a competitive price advantage over other major edible vegetable oils (Table 10.2). Thus, demand for soybean, palm, sunflower, and canola is expected to remain high and continue to dominate world oilseed trade. Even so, total worth of the major edible vegetable oils in 1988 to 1989 may be $26.91 billion. Hence, there is great economic incentive to sustain high production of all these commodities.

Table 10.1. Projected 1989 world supply and demand for major edible vegetable oils (U.S. Department of Agriculture, 1989)

Commodity	Production (MMT[a])	Consumption MMT)	Trade balance[b] (MMT)	Surplus (MMT)
Soybean	17.85	15.55	0.13	2.17
Palm	11.68	9.79	−0.12	2.01
Sunflower	8.01	7.44	0.06	0.51
Rapeseed[c]	7.96	7.19	0.31	0.46
Cottonseed	3.62	3.53	−0.03	0.12
Peanut	3.55	3.53	−0.03	0.05
Coconut	3.20	2.91	−0.05	0.34
Olive	2.37	1.80	0.00	0.57
Palm kernel	1.51	1.35	−0.02	0.18
Total	59.75	53.09	0.25	6.41

[a]MMT = million metric tons.
[b]Trade balance = exports minus imports.
[c]Rapeseed = edible canola.

Table 10.2. Projected 1989 world economic worth of major edible vegetable oils (U.S. Department of Agriculture, 1989)

Commodity	Price ($/MT[a])	Consumption (MMT[b])	Total value (Billion $)	Percent (%)
Soybean	441	15.55	6.86	25.5
Palm	372	9.79	3.64	13.5
Sunflower	474	7.44	3.53	13.1
Rapeseed	413	7.19	2.97	11.0
Cottonseed	570	3.53	2.01	7.5
Peanut	685	3.53	2.42	9.0
Coconut	556	2.91	1.62	6.0
Olive	1727	1.80	3.11	11.6
Palm kernel	558	1.35	0.75	2.8
Total		53.09	26.91	100.0

[a]$/MT = dollars per metric ton.
[b]MMT = million metric tons.

Although end of year stocks (surplus) of edible vegetable oils have remained at nearly a constant amount for the past decade, world consumption of vegetable oil has increased at a rate of about 1.5 MMT per year (U.S. Department of Agriculture, 1989). During the same period, however, U.S. edible vegetable oil consumption has increased at a much slower rate at about 0.15 MMT per year (Table 10.3). A result of the relatively slow growth in U.S. vegetable oil consumption has been the increased competition among oilseeds for market share. Such competition has led to changes in utilization of the major commodities. In 1980, soybean oil accounted for 78.4% of U.S. edible vegetable oil consumption, but soybean oil may account for only 73.4% of the total in 1989. The apparent decline in market share for soybean oil may be attributed to a 57.1% increase in use of sunflower, palm, and canola oils. Thus, under current market conditions, expanded utilization of a given commodity may result at the expense of another commodity. Such conditions further stimulate competition among oilseed crops and make evident the need to develop new or alternative uses for these commodities. No doubt the greatest opportunities in vegetable oil markets will be primarily through new industrial applications, such as the use of soybean oil to develop high quality printing inks for newspapers and other periodicals. New food product applications, however, may be limited by inherent properties of an oil, which are related to fatty acid composition.

Table 10.3. U.S. consumption (in million metric tons) of major edible vegetable oils (U.S. Department of Agriculture, 1989)

Commodity	1980	1989	Increase	% change
Soybean	4.134	4.945	0.811	19.6
Other[a]	1.140	1.791	0.651	57.1
Total	5.274	6.736	1.462	27.7

[a]Other = primarily sunflower, palm, and rapeseed.

As shown in Table 10.4, each major edible vegetable oil contains a characteristic fatty acid composition. Palm, coconut, and palm kernel have high proportions of saturated fatty acids and low proportions of polyunsaturated fatty acids; soybean, sunflower, and rapeseed (canola) exhibit low saturated/polyunsaturated (S/P) ratios. Canola, peanut, and olive oils contain high oleic (18:1) concentrations. Soybean and canola are the only major edible vegetable oils that contain linolenic acid (18:3). In general, oils with high saturated fatty acid content are used primarily in confectionery foods, and oils with high oleic (18:1) usually exhibit greater oxidative stability than do oils with high linoleic (18:2) or 18:3 when used as cooking oils. Hence, to expand utilization of a given vegetable oil, it may be necessary to alter the fatty acid composition by physical or chemical refining methods to effect desirable characteristics for a given food product. However, as our society becomes saturated with more affluent views, public opinion and genuine concern for the nutritional quality of food products will influence significantly the use of chemical methods and the type of vegetable oils that are perceived to be acceptable in food products. Agriculture and the food industry has been and will always be sensitive and subject to public perception of food quality. The greatest strength of our food production system is the ability to adapt to meet the needs and demands of the public. As a part of that system, more cost effective approaches are being developed to provide high quality natural vegetable oils for food products with improved nutritional value. Significant contributions to that goal have been made through classical plant breeding, where genetic variability for specific fatty acid traits may be exploited to create new germplasm resources that obviate the need for chemical refining treatments or that enhance nutritional benefits of vegetable oils.

One of the first examples of genetic modification of fatty acid composition in a crop species was in rapeseed (Downey and McGregor, 1975). Downey and others successfully bred low-erucic acid (22:1) rapeseed germplasm, which is now known as canola (Table 10.5).

Table 10.4. Fatty acid composition (as percent of total oil) of major edible vegetable oils (Weiss, 1983)

Commodity	$C_{12:0}$	$C_{14:0}$	$C_{16:0}$	$C_{18:0}$	$C_{18:1}$	$C_{18:2}$	$C_{18:3}$	Other	S/P[a]
Soybean	0.0	0.1	10.5	3.2	22.3	54.5	8.3	1.1	0.22
Palm	0.1	1.2	46.8	3.8	37.6	10.0	0.0	0.5	5.19
Sunflower	0.0	0.0	7.0	3.3	14.3	75.4	0.0	0.0	0.14
Rapeseed	0.0	0.0	4.3	1.7	59.1	22.8	8.2	3.9	0.19
Cottonseed	0.0	1.0	25.0	2.8	17.1	52.7	0.7	0.7	0.54
Peanut	0.0	0.0	11.0	2.3	51.0	30.9	0.0	4.8	0.43
Coconut	48.2	16.6	8.0	3.8	5.0	2.5	0.0	15.9	30.64
Olive	0.0	0.0	16.9	2.7	61.9	14.8	0.6	3.1	1.10
Palm kernel	50.9	18.4	8.7	1.9	14.6	1.2	0.0	4.3	66.58

[a]S/P = Ratio of saturate to polyunsaturated fatty acids.

Before that work, rapeseed was primarily an industrial oil because of high concentrations of 22:1, a fatty acid that causes antinutritional effects in animals. Selection of high-18:1 or high-18:2 safflower germplasm (Knowles, 1972) is another example. However, the greatest amount of progress in changing fatty acid composition of oils has been in soybean. Breeding programs at Raleigh, North Carolina, West Lafayette, Indiana, and Ames, Iowa have created many different variations on the normal fatty acid profile of soybean oil. Germplasm has been developed that may feature high or low concentrations of each of the five major fatty acids, including the saturated acids, palmitic (16:0) and stearic acids (18:0). Each of these accomplishments, combined with similar efforts in maize, sunflower, and peanut, have demonstrated that genetic alteration of vegetable oil composition to meet specific industrial needs and public demand is a viable approach that has great potential for expanding utilization, economic worth, and nutritional value of many different vegetable oils.

Development of Plant Germplasm with Altered Fatty Acid Composition

Although fatty acid composition of oilseed crops may be different, the basic biochemical mechanism for fatty acid synthesis is highly conserved in plants. Fatty acid synthetase is a multienzyme complex that catalyses the addition of two-carbon fragments from malonyl-

Table 10.5. Fatty acid composition (as percent of total oil) of genetically modified vegetable oils (Downey and McGregor, 1975; Knowles, 1972; Wilson, 1987)

Commodity	Type	$C_{16:0}$	$C_{18:0}$	$C_{18:1}$	$C_{18:2}$	$C_{18:3}$	$C_{22:1}$
Rapeseed	High 22:1	4.0	2.0	18.0	14.0	9.0	53.0
	Low 22:1	6.0	2.0	59.0	23.0	10.0	0.0
Safflower	High 18:2	8.0	2.0	18.0	72.0	0.0	0.0
	High 18:1	6.0	1.0	79.0	14.0	0.0	0.0
Soybean	High 18:3	13.0	3.0	15.0	56.0	13.0	0.0
	Low 18:3	10.0	3.0	28.0	55.0	4.0	0.0
	Low 18:3	11.0	4.0	47.0	34.0	4.0	0.0
	High 18:0	8.0	28.0	20.0	36.0	8.0	0.0
	Low 16:0	5.0	4.0	49.0	36.0	6.0	0.0

CoA to an initial molecule of acetyl-CoA. To initiate the reaction, the CoA-intermediates are converted to acyl-carrier-protein (ACP) derivatives, which are bound to the enzyme complex. The acyl-ACP chain then is elongated to form 12:0-ACP (lauric acid), 14:0-ACP (myristic acid), or 16:0-ACP. The latter product then may be elongated to 18:0-ACP by an additional enzyme, and that product may become a substrate for an 18:0-ACP desaturase, which produces 18:1-ACP. Endogenous acyl-ACP molecules are hydrolyzed easily from ACP to free acids by thiolases. These acids then must be converted to acyl-CoA derivatives before esterification to glycerol in the formation of phospholipids and triacylglycerols. Synthesis of 18:2, and 18:3 in certain species, is catalyzed by separate desaturase enzymes that act upon 18:1, which is esterified to a phospholipid. Phospholipids serve as membrane (structural) lipids and also are metabolized actively to form triacylglycerol (TG), a storage lipid and the major glycerolipid component of oil. These reactions account for the majority of fatty acids and glycerolipid structures found in the major edible oilseeds. Some knowledge of these complex biochemical pathways is essential for the development of plant breeding strategies, because current information on genetic control of fatty acid composition is extremely superficial (Wilson, 1987).

With regard to the five major fatty acids in vegetable oils (16:0, 18:0, 18:1, 18:2, and 18:3), there is limited documentation on specific genes or the number of genes that may be involved in synthesis of a given fatty acid in any crop. Certain information on the inheritance of these fatty acids, however, is known. In soybean, 16:0 concentration is believed to be determined by two alleles at a single gene locus (Bubeck et al., 1989; Erickson et al., 1988a). The gene symbol fap_1 has been assigned to alleles at this locus that enact expression of low 16:0 (5%); the symbol fap_2 denotes alleles that confer expression of high 16:0 (16%) in the seed oil (Erickson et al., 1988b). Inheritance of low or high 16:0 in soybean seed seems influenced by the genotype of the embryo. Similar conclusions have been formed concerning the inheritance of 18:0 in soybean. High (28%) or low 18:0 (3%) may be determined by alleles at the "Fas" locus, with gene expression also being influenced by the genotype of the seed (Bubeck et al., 1989; Erickson et al., 1988a; Lundeen et al., 1987). Genetic regulation of 18:0 in safflower, however, may be a function of two independent alleles at the "Ol" and "St" loci (Ladd and Knowles, 1971). In the homozygous state, the *OlOlstst* genotype produces high 18:0 (10%) in safflower.

Genetic regulation of 18:1 concentration among oilseed species is more complex. In safflower, homozygous recessive alleles at the *Ol* locus plus homozygous dominant alleles at the *St* locus, giving an *OlOlStSt* genotype, effect high 18:1 (79%) concentrations (Knowles, 1972). In sunflower, homozygous (partially) dominant alleles at the *Ol* locus with recessive alleles at a modifying gene locus *Ml* having unknown function determine the trait. These *OlOlMlMl* genotypes produce 82% 18:1 (Miller et al., 1987). Control of 18:1 concentrations in soybean is less well defined, but high 18:1 (47%) results when genes regulating desaturation of 18:1 to 18:2 are in a homozygous recessive condition (Wilson and Burton, 1986). In each of these oilseed species, 18:1 seems to be determined by maternal influences with no indication of cytoplasmic effects (Erickson et al., 1988).

Synthesis of the saturated fatty acids and 18:1 in seed tissue is localized in plastids, an organelle functionally related to chloroplasts in leaf tissue. Although plastids contain genetic information (plastome), the lack of cytoplasmic effects on genetic control of these fatty acids indicates that these enzymes are encoded, respectively, by genes in the nuclear genome. Polyunsaturated fatty acids, 18:2 and 18:3, also may be synthesized in the plastids; however, in seed, these acids are synthesized primarily in the cytoplasm in association with the endoplasmic reticulum. Recent evidence has shown that 18:2 concentration is determined by genes encoding the 18:1 desaturase system in soybean, which seems to be influenced by the maternal genotype (Wilson and Burton, 1986). An 18:2 desaturase system, present in soybean and rapeseed, is believed to be governed by alleles at a single locus, *Fan*. Expression of the 18:3 trait is determined by the genotype of the embryo (Rennie et al., 1988; Wilcox and Cavins, 1985; Wilson and Burton, 1986). Genes controlling both of these desaturase systems exhibit additive genetic effects. Very low concentrations of 18:3 (3.5%) result when homozygous recessive alleles occupy both loci.

An immediate consequence of manipulation of gene systems that affect fatty acid composition in oilseeds is alteration in the type and amount of acyl-CoAs available for glycerolipid synthesis. However, incorporation of these molecules in the final product of glycerolipid metabolism, TG, also is influenced by genetic effects upon enzymes involved in phospholipid synthesis. The pathways of glycerolipid metabolism are shown in Figure 10.1. At the beginning of this sequence, Nishida et al. (1987) have reported at least two isozymes of glycerophosphate acyltransferase with different substrate specificities that determine the type of acyl-CoA that is esterified at the *sn*-1 position of glycerol-3-phosphate. In addition, Ichihara et al. (1987) have shown selective utilization of 1-acylglycerol phosphate and acyl-CoA species by acylglycerol-phosphate acyltransferase. Hence, the relative affinity that these enzymes exhibit for different substrates may determine the assortment of metabolically active diacylglycerol molecular species formed from phosphatidic acid. Stymne and Stobart (1984) also have shown that acyl-CoA:lysophosphatidylcholine acyltransferase affects the composition of the acyl-CoA pool that is used to esterify diacylglycerol by diacylglycerol acyltransferase (DGAT), the enzyme that catalyses TG synthesis. Finally, Kwanyuen et al. (1988) have found that DGAT per se demonstrates selective utilization of substrates in soybean. These biochemical reactions collectively interact to determine the composition of TG molecular species that constitute storage lipid (oil) in an oilseed. Therefore, genetic manipulation of fatty acid composition at the level of fatty acid synthesis is only a first step in tailoring oilseed composition for a given purpose. Many other points in the biochemical pathways downstream from fatty acid synthesis also come into play in terms of genetic regulation of lipid metabolism. At this time, much of this process is understood poorly; but TG molecular species analysis in soybean germplasm selected for low 18:3 (Table 10.6) clearly shows that much may be gained in terms of significant alteration of the physical properties of edible vegetable oils through genetic control of lipogenic enzymes, such as DGAT.

Future Research Opportunities

Advances in plant genetics and biochemistry during the past decade have shown that it is possible to create oilseed genotypes with significantly altered oil composition. These breakthroughs now are coming into practical application in the food industry. As public awareness of the benefits of these natural products increases, there will be greater demand for additional improvements, especially in human nutrition. Competition among oilseeds also will necessitate continued progress to create special characteristics in oil composition. Oilseed crops in which such progress is not made will most certainly lose market share in edible oilseed trade. Future advances in this research, however, will require more sophisticated approaches that incorporate basic information into useful technologies. Scientists in several disciplines, including molecular genetics, must cooperate to accomplish these goals. One goal may be to alter the structure of proteins like DGAT so that the enzyme produces an oil that is similar to another oilseed that is in high demand. An example may be a soybean that naturally synthesizes cocoa butter. This objective may be accom-

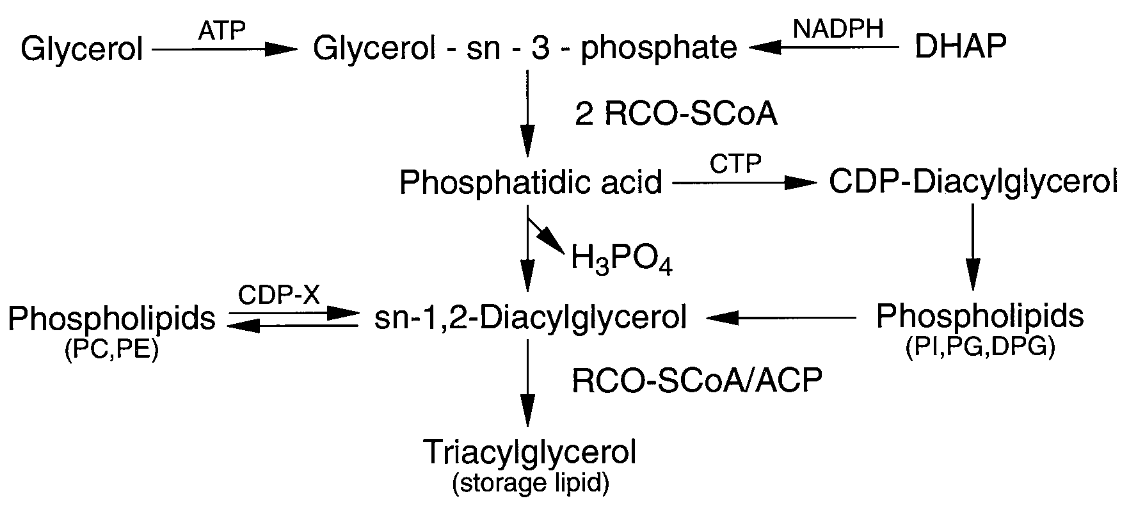


Figure 10.1. **Pathways for complex glycerolipid synthesis in plants.**

DHAP = dihydroxyacetonephosphate
RCO-SCoA = acyl-Coenzyme A
CTP = cytosine triphosphate
CDP = cytosine diphosphate
CDP-X = CDP-choline or CDP-ethanolamine
PC = phosphatidylcholine
PE = phosphatidylethanolamine
PI = phosphatidylinositol
PG = phosphatidylglycerol
DPG = diphosphatidylglycerol or cardiolipin;
RCO-SCoA/ACP = acyl thioester with Coenzyme A or Acyl Carrier Protein

Table 10.6. Triacylglycerol molecular species analysis from developing soybean cotyledons[a] (Kwanyuen and Wilson, 1991)

	Molecular Species		
Genotype	18:1-18:1-16:0 18:1-18:1-18:1 18:1-18:1-18:2	18:2-18:2-16:0 18:2-18:2-18:1 18:2-18:2-18:2	Total
N78-2245	58.3	14.6	72.9
N85-2176	45.3	28.3	73.6
N85-2131	37.7	34.2	71.9
N85-2124	26.8	43.7	70.5
PI123440	21.7	46.7	68.4
LSD0.05	9.4	8.2	1.3

[a]From seed harvested at 30 days after flowering.
[b]Percent of total triacylglycerol composition.

plished by cloning the genes for DGAT from copra into soybean or by site-specific mutagenesis of the existing protein in soybean. Still, to have a useful technology, the biochemical mechanism of the enzyme must be known and classical plant breeding strategies will have to be implemented to develop agronomically acceptable cultivars. Many of the tools needed to achieve tasks of that magnitude already are available. As our understanding of the system improves, the potential for significantly effecting beneficial change in the quality, utilization, economic worth, and nutritional value of edible vegetable oils will become a high priority issue rather than merely a novel experiment.

11 Effect of Processing on Vegetable Oil Composition

Summary

Current processing methods effectively remove oils from vegetable sources by pressing and extraction with hexane. Complete removal of hexane, minor components, and oxidized by-products that affect flavor and performance are achieved by distillation, aqueous washes, adsorption, and combined steam and vacuum. The resulting oils are approximately 99% unaltered triacylglycerol compounds, and the remainder is principally plant sterols and tocopherols. The fatty acid composition can be altered to improve stability and function through hydrogenation, rearrangement, and crystallization processes.

Introduction

The vegetable oils are obtained from oilseeds or pulps by pressing, extraction with hexane, or by a combination of pressing and extraction. These processes remove crude oils that are composed of triacylglycerols (usually more than 97% of the oil) and minor components including fatty acids, plant sterols, vitamin E, phospholipids, such as lecithin, waxes (esters of fatty acids and fatty alcohols), and chlorophyll. Processing of these crude oils removes many of the minor components and can be used to alter the composition of the triacylglycerols to improve the stability or the functionality of the oils.

Pressing and Extraction

Hexane is used as the solvent in virtually all oilseed extractions because of its miscibility with triacylglycerols and the relative ease with which it can be removed completely from the oil and the residual meal. The hexane is recovered to be used again in oil extraction. Soybean, canola, cottonseed, and corn oils (from the germ) are obtained by extraction with hexane. Palm, palm kernel, coconut, olive, and peanut oils are obtained with presses that separate the oil from the plant pulp source.

Removal of Minor Components

The removal of some of the minor components improves the appearance, taste, and performance of the oils. Slightly acid water is used to remove phospholipids and traces of proteins in a process termed degumming. Caustic solutions then neutralize the oil, and resulting free fatty acid soaps and glycerol are washed from the oil. This step is referred to as alkali refining. The next step is bleaching, which uses dispersed clay particles as an adsorbent to remove carotenes, chlorophyll, other pigments, trace metals, and soaps. Deodorization, a process utilizing steam and a vacuum, removes off-flavor oxidized products, such as peroxides and aldehydes. In addition, residual traces of fatty acids and pesticides are removed in the deodorization step. Most tocopherols and plant sterols remain in the oils during the degumming, alkali refining, bleaching, and deodorization processes. These tocopherols are a significant source of dietary vitamin E. The plant sterols, the principal unsaponifiable components, are metabolically inert compounds that have been associated with a decrease in plasma cholesterol when ingested at high amounts (Lees et al., 1977).

Hydrogenation

Hydrogenation of an oil involves the chemical bonding of hydrogen at sites of unsaturation of the constituent fatty acids through the use of a nickel-based catalyst, hydrogen, and pressure. Hydrogenation is used to modify the triacylglycerol fatty acids to increase the oxidative stability or the melting point of fat.

The heating of a fat in normal frying conditions eventually leads to peroxides, peroxide degradation products, and polymers of triacylglycerol molecules. These products form most rapidly in fats that contain high ratios of unsaturated fatty acids. Although the amounts of these thermal and oxidation breakdown products produced in normal cooking conditions are not a health concern (Artman, 1969), they are responsible for undesirable flavors and darkening of the oils.

Hydrogenation decreases the number of double bonds that participate in the peroxidation and polymerization reactions and results in a fat that is more stable than the unhydrogenated fat.

Hydrogenation changes the texture of fats by converting a portion of the low- melting cis-unsaturated fatty acids to higher melting saturated acids in the triacylglycerols. In addition, some higher-melting trans-unsaturated compounds may be formed in small quantities under normal conditions. These higher melting trans fatty acids provide the solid and semi-solid fats that are used in combination with the more unsaturated liquid fats in margarines, spreads, and shortenings. Solid fat components are important in baking applications and are necessary for the texture of spreads and confections.

The catalyst used in the hydrogenation process, usually a formulation of nickel, can be selected to direct the reaction either toward predominantly saturated fatty acids or toward high ratios of trans fatty acids in the triacylglycerol products. In addition, the catalyst can result in the shift of the position of the double bonds on the fatty acids. The catalyst is removed completely by filtration from the oil. The trans fatty acids produced by hydrogenation have been studied thoroughly and found to present no risk to health in a nutritionally adequate diet (Senti, 1985).

Interesterification

Another process-related modification of the composition of vegetable oils is that of interesterification. This process, also termed rearrangement, utilizes a base catalyst to hydrolyze and then resynthesize triacylglycerols. This procedure changes the structure of a triacylglycerol from one with a particular fatty acid in a single position (e.g., lard, which comprises principally palmitic acid in the 2-position of the triacylglycerol) to a more random distribution of fatty acids among the three positions of the molecule. Functionality of lard in baking improved with its rearrangement to the random structure, and this process has been used commercially with lard.

A type of this rearrangement reaction can result in a change in the overall fatty acid composition of the triacylglycerol, as well as in its structure. If the rearrangement takes place at low temperature, high melting species, such as the triacylglycerols containing all stearic and palmitic acids, can precipitate and be removed from the system. The resulting fat thus would be enriched in compounds with unsaturated fatty acids through this process that is termed "directed rearrangement." This reaction is seldom used in today's fat processing, because a wider variety of fat compositions can be obtained from natural oils without rearrangement.

Crystallization

Some oils, such as sunflower oil, contain small but significant quantities of wax esters (compounds of fatty acids and fatty alcohols). These waxes crystallize at low temperature, and it is desirable to remove them by crystallization and filtration to improve the appearance of the oil when refrigerated. Oils also can be fractionated by crystallization at low temperatures (winterization) into solid and liquid fractions to enrich either the saturated or the unsaturated fatty acid ratios as the high- and low-melting fractions, respectively.

12 Tailored Triacylglycerols and Fat Substitutes

Summary

Triacylglycerols synthesized from medium-chain fatty acids are used as substitutes for normal long-chain fats in individuals who have an insufficient supply of fat-digesting lipases. There are numerous types of fat substitutes that are either commercially available or are being developed. Water-based emulsions, gels, and suspensions of carbohydrate and protein can replace fat in food emulsion systems. Triacylglycerol-like fat substitutes that provide the taste and texture of fats without the high caloric density are being developed and considered for approval as food additives.

Introduction

Tailored triacylglycerols and fat substitutes have been developed to provide edible fat-based foods with certain advantages over foods prepared with the traditional fats. This discussion of these materials will address separately (1) tailored triacylglycerols, (2) combinations of water with carbohydrate or protein that can replace fat-based emulsions in foods, and (3) triacylglycerol-like, zero-calorie fat substitutes that provide the appearance, texture, and heat stability of natural fats.

Tailored Triacylglycerols

Typical vegetable oils are triacylglycerols with fatty acid compositions comprising fatty acids of 12- to 18-carbon atoms in chain length. In normal individuals, a sufficient amount of the digestive enzyme, pancreatic lipase, is present, and fat digestion and absorption are typically complete. In cases of lipase insufficiency, such as in premature infants and cystic fibrosis patients, normal fat digestion is incomplete and undesirable gastrointestinal symptoms can result. It has been found that triacylglycerol oils that are synthesized from medium-chain length fatty acids (eight- or ten-carbon atoms) are digested and absorbed even in cases when lipase deficiency would result in malabsorption of the normal, long-chain fatty acid triacylglycerols (Greenberger et al., 1966).

Medium-chain triacylglycerols are synthesized by the reaction of glycerol with the octanoic and decanoic acids obtained from the processing of coconut oil fatty acids. The resulting triacylglycerol is a clear liquid oil that resembles normal vegetable oils in appearance and taste. These triacylglycerols have been utilized frequently in formulas for premature infants and in diets for subjects with fat malabsorption problems.

Triacylglycerols synthesized from mixtures of medium- and long-chain fatty acids have been reported to have some advantages over normal fats in total parenteral nutrition situations. An appropriate balance of the ratio of long- to medium-chain fatty acids may provide the optimal rate of clearance from the blood as well as a decrease in sepsis in total parenteral nutrition patients (Heird et al., 1986).

A relatively new development may allow the commercial application of lipase in the synthesis of tailored triacylglycerols. Lipase immobilized on solid adsorbents has been used to prepare triacylglycerols with specific fatty acids bonded to specific positions of glycerol. This procedure may allow the synthesis of triacylglycerols with fatty acid composition and fatty acid position that are similar to those of unique natural triacylglycerols as in cocoa butter (McCrae, 1983).

Carbohydrate- and Protein-Based Fat-Substitute Emulsions

Numerous foods have been developed with concentrations of fat that are significantly less than those normally associated with these items. Margarine, ice cream, and salad dressing formulations have had their fats replaced with combinations of water, emulsifiers, and carbohydrate-based thickeners. The resulting products—bread spreads, ice milk, and light dressings—are lower in fat and calories compared with their traditional counterparts. These fat substitute emulsions may include water, carrageenan, several gums, maltodextrins, polyglycerol esters, or other emulsifiers.

A somewhat different approach to the replacement of fat in emulsion-based foods has been the development of water suspensions of protein microspheres. Simplesse™, the trade name for one of these materials, is a formulation of whey or egg white microspheres that are less than 2 μm in diameter (Anonymous, 1989). Suspensions of these microspheres in water are reported to provide a creamy texture that mimics that of a fat-based emulsion. The composition of Simplesse™ is one-third protein and two-thirds water, with a resulting caloric density of 1.3 kcal/g. The generally recognized as safe status (GRAS) for Simplesse™ was approved by the Food and Drug Administration in February of 1990.

Although these fat substitute emulsions, based on carbohydrate and protein, are useful in formulating many fat-reduced products with the viscosity and creaminess of higher fat foods, they do not provide all of the properties of normal fats. They are unable to function in high fat products, such as shortening and cooking oils, because of the instability of the emulsions at the temperatures of frying and baking. As a result, the triacylglycerol-like fat substitutes discussed below also have been the focus of developmental efforts.

Triacylglycerol-Like Fat Substitutes

Fat substitutes with the physical properties of triacylglycerols have been formulated to provide the taste, texture, appearance, and heat stability of normal triacylglycerol fats and oils but with little or no utilizable energy content. These fat substitutes are resistant to the intestinal lipases that split normal triacylglycerols into digestion products that can be absorbed. The fat substitutes are formulated so that the mouth and palate will perceive them as normal triacylglycerol fats, whereas the gastrointestinal tract is unable to absorb them. This characteristic of nonabsorbability prevents the body from utilizing the chemical energy contained in the fat substitutes and, when completely nonabsorbed, they may appropriately be termed "zero-calorie."

Examples of compounds currently being considered as fat substitutes are:

1. Olestra, a mixture of hexa-, hepta-, and octa-long-chain fatty acid esters of sucrose, made from sucrose and vegetable oil fatty acids (Bergholz, 1989).
2. Carballylic esters of fatty alcohols, termed retrofat, because it is synthesized from fatty alcohols and a tricarboxylic acid (compared with fatty acids and a triol in the case of triacylglycerols) (Bieber, 1989).
3. Malonate esters, long-chain fatty alcohol esters of the dicarboxylic acid, malonic acid (Spearman, 1989).
4. Propoxylated glycerol, propylene oxide polymers of varying chain length, esterified with glycerol (Cooper, 1989).
5. Silicon oils, oils with molecules of silicon backbones rather than hydrocarbon chains (Hashim, 1989).
6. Wax esters, ester compounds made from long-chain fatty acids and long-chain fatty alcohols as those found in jojoba oil (Decombaz et al., 1984).

Currently, only olestra is the subject of a Food Additive Petition before the FDA. This petition requests approval of its use as a fat substitute for production of fried snacks, including potato chips and corn chips. Also specified in the petition is the supplementation of olestra with vitamin E to maintain nutritional equivalence with the vegetable oils that olestra will replace. As of this writing, none of these triacylglycerol-like fat substitutes is yet approved for food use by the general population. Approval for any of these materials will require the establishment of their safety.

13 The Role of Dietary Fat in Cardiovascular Diseases

Summary

Cholesterol is a vital component of the biochemical economy, being present in every cell membrane and acting as precursor of bile acids, corticosteriods, and sex hormones. It comprises about 0.2% of the body weight, and about two-thirds of the total body cholesterol is distributed equally in the brain and nervous system, muscle, and connective tissue plus body fluids other than blood.

There are three major factors associated with the risk of coronary heart disease, namely, elevated blood pressure, cigarette smoking, and elevated serum cholesterol. These and some of the other important risk factors, such as diabetes or obesity, are amenable to control, but one of the other important factors, genetics, is not.

A serum cholesterol concentration in excess of 240 mg/dl (6.2 mmol/l) is considered a major risk for heart disease. In this connection it should be noted that serum or plasma cholesterol varies with time, season, and stress, and single determinations are not good indicators of risk. The concentration of cholesterol in the blood is not affected strongly by dietary cholesterol, but is dependent on the degree of saturation of the dietary fat. Trials, dietary and pharmaceutical, conducted to decrease cholesterol concentrations have led to fewer coronary events in the test groups but not to differences in total (all cause) mortality. The death rate from coronary heart disease in the United States has been dropping steadily since 1968. Changes in diet over that period have not been as dramatic.

Discussion

Cholesterol is one of the most common compounds found in the human body. It is present as free cholesterol in every cell membrane; within the cell, it can be present in the free or esterified form. The human body contains about 0.2% cholesterol; thus, the hypothetical 70-kg man has 140 g of cholesterol in his body. Three sites contain about two-thirds of all the body's cholesterol. These sites are the brain and nervous system (22%), connective tissue and fluids other than blood (22%), and muscle (21%). Of the remaining cholesterol, 11% is in the skin, 8% in the blood, 5% in bone marrow, 4% in liver, and the other 7% is in the alimentary tract, lungs, kidneys, adrenal glands, and other sites.

Most of the circulating cholesterol is derived from endogenous synthesis, principally in the liver, which can synthesize more than a gram of this sterol daily. The remainder is derived from the diet. In addition to its presence in cell membranes, cholesterol is the precursor of several substances of critical importance to human health. The major products of cholesterol catabolism are the bile acids, which are synthesized in the liver and secreted into the intestine, where they are essential for normal digestion and absorption of dietary fat. In the skin, 7-dehydrocholesterol, a precursor of cholesterol, also is a precursor of vitamin D_3. The adrenal glands convert cholesterol to hormones, such as cortisone, which regulate glucose and mineral balance. In the gonads, cholesterol is converted to the appropriate sex hormone. Cholesterol is also critical to the structure of the myelin sheath, which protects nerves.

Cholesterol is insoluble in water, and its transport in the blood is facilitated by its being a part of the complex lipid-protein agglomerates called lipoproteins. The lipoproteins of plasma are commonly classified by their hydrated densities and are designated as (1) chylomicrons, which are composed primarily of triglycerides, and whose major function is the transport of dietary lipids; (2) very-low-density lipoproteins (VLDL), which contain about 50% triglyceride and 22% cholesterol and which primarily transport endogenous lipids; (3) low-density lipoproteins (LDL), which contain most of the circulating cholesterol (46% of all LDL is cholesterol) and whose functions involve transport of cholesterol and regulation of cholesterol metabolism; and (4) high-density lipoproteins (HDL), whose major component is protein (50%) and which can transport cholesterol away from peripheral tissues.

Because the plasma lipoproteins are defined by their physical, not chemical, properties, it is reasonable that subfractions, which demonstrate similar hydrated densities, may have varying composition, and, indeed, we now find reports of LDL fractions, for instance, that contain different amounts and types of cholesterol esters.

Despite its pivotal role in normal human and animal physiology, cholesterol is known to the public because of its role in the etiology of coronary heart disease. Studies carried out in the second decade of this century showed that rabbits fed cholesterol developed atheroma (fatty lesions) in their aorta and coronary arteries. In humans, it usually is conceded that high concentrations of cholesterol in the blood were predisposing to heart disease. The concept of risk factors for coronary heart disease arose from the Framingham Study (Kannel et al., 1961) in which a relatively large population was studied over a long period of time. Correlations were drawn between several physiological and behavioral parameters and emergence of heart disease. The principal risk factors discerned from the Framingham Study, as well as from other studies, are elevated plasma cholesterol, elevated blood pressure, and cigarette smoking. Some authors have identified over 200 physiological or behavioral parameters that can be regarded as risk factors. It is important to point out that risk factors are statistical rather than medical diagnostic indicators. The Framingham Study (Truett et al., 1967) showed that a smooth curve was obtained when concentration of plasma cholesterol was plotted against incidence of coronary disease and from this was developed the "Cholesterol Hypothesis," which stated that a decrease in risk could be the result of a decrease in cholesterol concentration. Measurement of blood cholesterol is a relatively simple, if technically variable, process. The concentration of cholesterol in serum or plasma, however, is not stable. Serum cholesterol may vary with time of day, season of the year, and amount of stress. This knowledge of effectors makes it mandatory to be certain that serum cholesterol values are representative of the individual subject, rather than being point aberrations that result from any of a number of extraneous conditions.

The question of what constitutes a dangerous concentration of cholesterol in blood plasma is also a matter of discussion. The Pooling Research Group asserted in 1978 that a cholesterol concentration above 240 mg/dl constituted a real risk for heart disease but found little or no relation below concentrations of 220 mg/dl. The National Cholesterol Education Project also has fixed 240 mg/dl as the danger point but suggests that ideal concentrations should be below 200 mg/dl. In addition, the National Cholesterol Education Project suggests that concentrations of LDL- and HDL-cholesterol also be measured, because current data indicate that elevated concentrations of LDL may be a more accurate indicator of cardiovascular risk than is total serum or plasma cholesterol. Elevated HDL-cholesterol is regarded as a positive or protective risk factor, although HDL-cholesterol concentrations are not as labile as those of LDL-cholesterol. Eventually, concentrations of apolipoproteins may provide the most accurate assessment of risk.

The point of contention regarding blood cholesterol centers on the role(s) of dietary cholesterol. Few would deny that elevated blood cholesterol is a risk factor, but the role of dietary cholesterol as it may influence blood cholesterol is under vigorous debate. Gertler et al. (1950) surveyed cholesterol intake and serum cholesterol concentrations in men with coronary heart disease and control subjects and found that those with coronary disease had significantly higher serum cholesterol concentrations; there was, however, no relation to their cholesterol intake. Moreover, the Framingham Study (Dawber et al., 1982) found no relationship between cholesterol intake and serum cholesterol concentrations. In fact, subjects who ingested 1.4 or 9 eggs per week had similar cholesterol concentrations. A study of diet and risk in men who did or did not have coronary incidents in three large ongoing studies (Framingham, Puerto Rico, and Hawaii) found significant differences in calories, complex carbohydrate, and alcohol intake but none in fat or cholesterol (Gordon et al., 1981). A number of epidemiological studies carried out in relatively large numbers of free-living individuals have shown that addition of eggs to the normal diet did not affect the serum cholesterol concentrations. In contrast, studies carried out in subjects maintained in incarceration (e.g., prison and metabolic ward) show a direct relation between dietary and serum cholesterol. The difference in results may reflect the stress of incarceration.

The greatest dietary influence on plasma cholesterol is exerted by the type of fat in the diet. Data from animal and human studies indicate that diets rich in saturated fat lead to elevated plasma cholesterol. In most studies, the amount of dietary fat is in the range of 15 to 40% of total calories. Keys (1965) and Hegsted (1965) and their colleagues formulated equations to predict changes in plasma cholesterol from changes in the fatty acid composition of dietary fat. Assuming a diet comprising 2,556 kcal/day and containing 300 mg of cholesterol and assuming substitution of a given fat for 50 g of soybean oil (17.6% of energy), it can be calculated that cottonseed oil would increase cholesterol concentrations by 9.7 mg/dl and coconut oil, by 45.7 mg/dl. The anomalous effects of oleic acid (which decreases cholesterol) and stearic acid (which has virtually no effect) are to be noted. It also should be recognized that the serum represents only one pool of cholesterol. Gerson et al. (1961) found that feeding

14 The Role of Dietary Fat in Blood Pressure Regulation

Summary

Regulation of blood pressure by dietary means represents an important approach toward decreasing morbidity and mortality of cardiovascular disease. A nutrient class that seems to have a beneficial effect on blood pressure is polyunsaturated fatty acids. Linoleic acid (n-6) consumed at amounts of 6-10% of energy decreases systolic and diastolic blood pressure in mild-to-moderate hypertensive males and females. Omega-3 fatty acids from fish oil also decrease blood pressure in male hypertensive subjects when fed at pharmacological amounts.

Introduction

In recent years, dietary studies in humans and animals support the concept that dietary polyunsaturated fatty acids (PUFA) decrease blood pressure in high-normal and mild-to-moderate hypertensives. The literature includes dietary intervention studies on free-living populations, community-based dietary studies, metabolic unit experiments, and epidemiological studies (Iacono and Dougherty, 1990).

Early work demonstrated that low-fat diets consisting of typical foods of the United States improved atherogenic and thrombogenic indices. In addition, it has now been shown that similar diets also can decrease blood pressure. These improvements in specific risk factors related to cardiovascular disease were accomplished by decreasing the saturated fat in the diet and increasing the polyunsaturated fats. Generally speaking, a decrease of saturated and monounsaturated fat in the diet can be achieved easily. At the same time, the addition of PUFA from typical seed oils raise the polyunsaturated fatty acid to saturated fatty acid ratio (P:S) of the diet.

Dietary PUFA and Blood Pressure in Humans and Animals

Practically all studies in which diets were enriched with ω-6 PUFA in rats indicated that blood pressure was decreased, regardless of the strain of rat used. Usually, the vasodilator prostaglandins (PGs) PGI_2, PGE_2, and 6-keto-$PGF_{1\alpha}$ also increased in either kidney, aorta, blood, or urine, suggesting that linoleic acid was the precursor of these eicosanoids (Iacono and Dougherty, 1990). Dietary linoleic acid also decreased blood pressure, regardless of whether the rats were salt-loaded before feeding the linoleic acid. This lowering effect was mediated through the increased concentrations of PG, which led to increased water and salt excretion by kidney. It has been proposed that this physiological mechanism accounts for the lowered blood pressure.

A series of studies in humans also support the concept that increased dietary linoleate from typical seed oils decreases blood pressure (Weinsier and Norris, 1985.) The studies reported include dietary intervention trials on free-living populations. The major concerns of these studies were to define natural diets that promote health and demonstrate improvements in atherogenic and thrombogenic indices as well as improve blood pressure. In many instances, these improvements were accomplished by decreasing the fat content of the diet from about 40% of energy with a P:S of 0.3 to about 25% of energy with P:S of 1. The major fatty acid constituents of animal products, saturated and monounsaturated, were decreased by trimming the visible fat from meat and decreasing the fat content of dairy products. The PUFA were increased in the diet by the addition of seed oils. As a consequence of feeding these diets, a clear interpretation of the effect of ω-6 fatty acids on blood pressure was masked by the simultaneous decrease in dietary saturated and monounsaturated fatty acids and by the increase in PUFA (Figure 14.1). In a preliminary report, this issue was clarified in a metabolic study designed to control the qualitative and quantitative intake of fatty acids (Figure 14.2) (Iacono and Dougherty, 1990), where linoleic acid (ω-6) was found to be the fatty acid responsible for the lowering of blood pressure in man. Further studies need to be conducted to confirm this finding.

A number of studies where ω-3 fatty acids (eicosapentaenoic and docosahexaenoic) were supplemented in the diet also have demonstrated a lowering of systolic and diastolic blood pressure (Iacono and Dougherty, 1990). It is too early, however, to draw firm conclusions from these data because of a lack of nutritional control. Efforts to resolve this issue currently are underway.

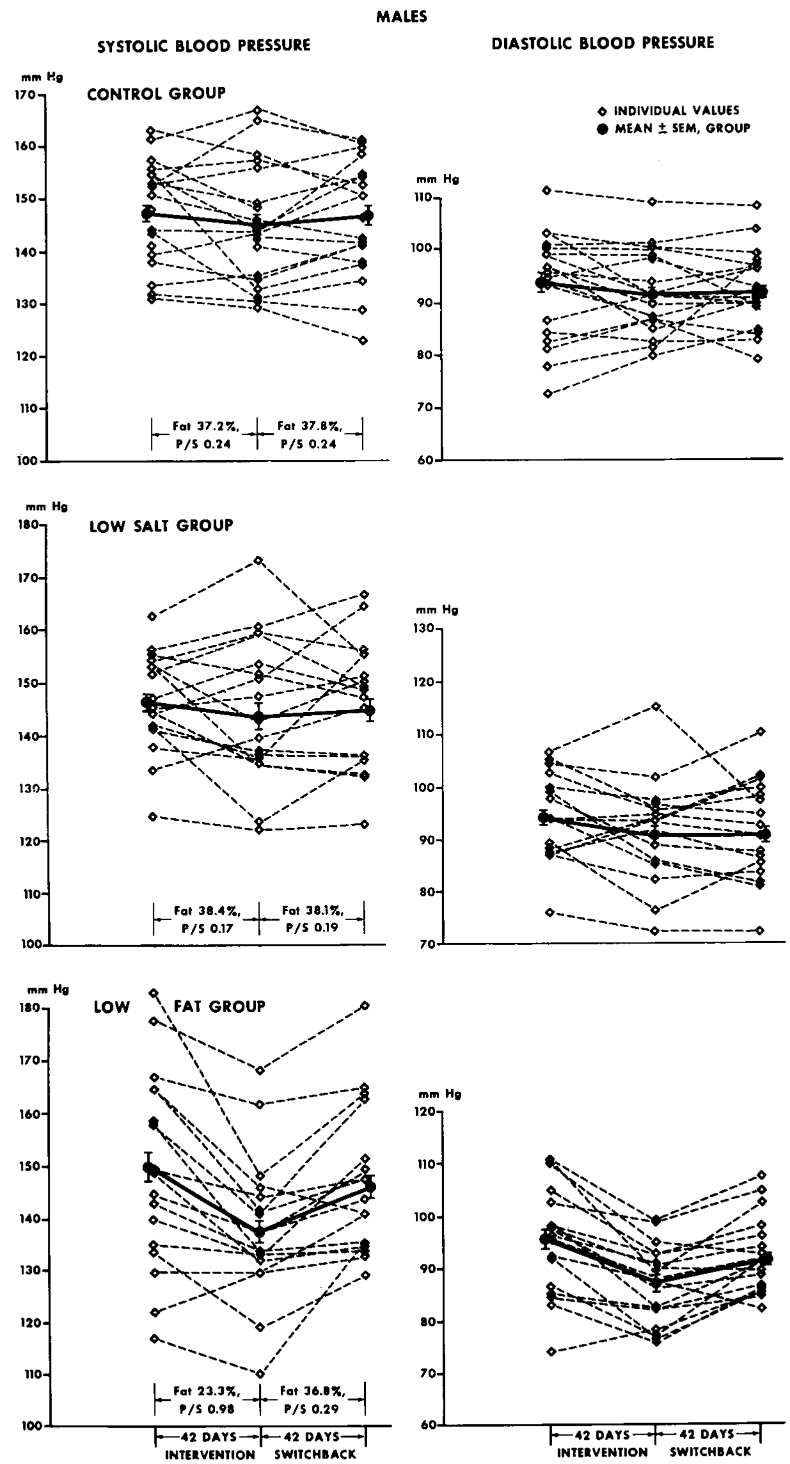


Figure 14.1. Systolic and diastolic blood pressure of three groups of male subjects in a community-based dietary intervention study. Systolic and diastolic blood pressure of the low-fat group at the end of the intervention period was significantly different from the values at the end of the switchback period (P<0.001) (Puska et al., 1983).

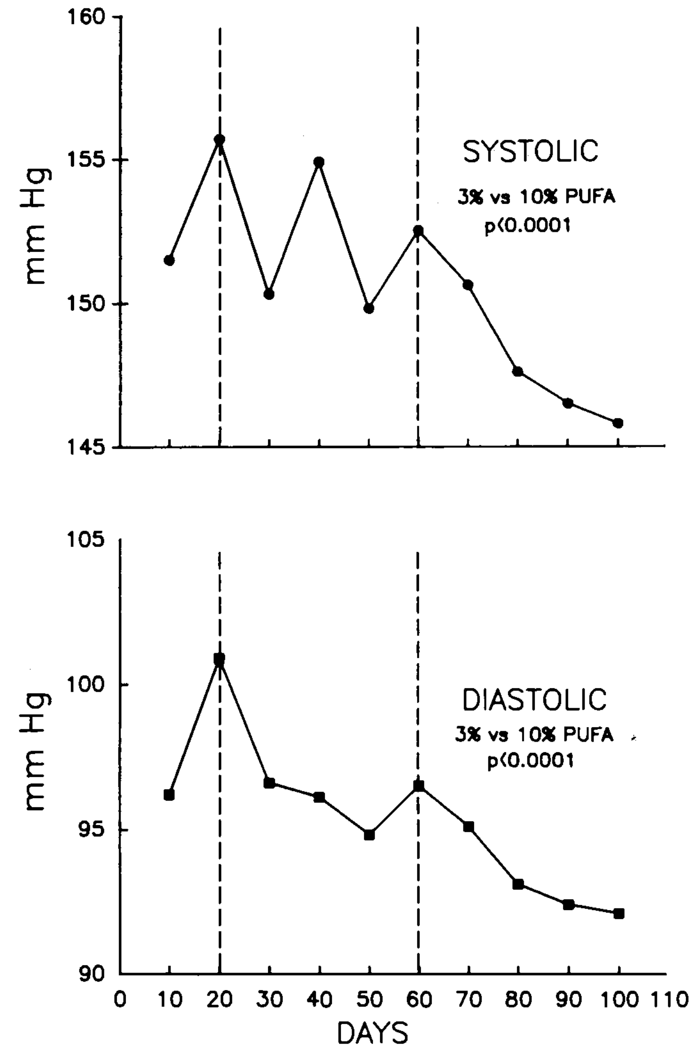


Figure 14.2. Systolic and diastolic blood pressure of mild-to-moderate hypertensive male subjects in a metabolic unit study:
0 to 20 days, stabilization;
21 to 60 days, 10 en% saturated and 10 en% monounsaturated fat, and 3 en% PUFA;
61 to 100 days, 10 en% saturated and 10 en% monounsaturated fat, and 10 en% PUFA
(Iacono and Dougherty, 1990). (En% = percentage of total energy intake.)

15 The Role of Dietary Fat in Development of Obesity

Summary

Obesity is a serious public health problem. Studies in animals and humans have shown that consumption of a high-fat diet is associated with development and/or maintenance of obesity in some individuals. Researchers are now unraveling the complex interactions among orosensory properties of fats, metabolic factors, and genetic background that determine the extent to which consumption of a high-fat diet contributes to obesity.

Obesity Incidence

The simplest definition of obesity is a condition in which there is an excessive amount of body fat. To establish if an individual is obese, then, requires a measure of body fatness and a standard for comparison (Bray, 1976; Jequier, 1987; U.S. Department of Health and Human Services, 1988). Methods commonly used in research to estimate body fatness include underwater weighing and use of calipers to measure subcutaneous skin-fold thickness (Bray, 1976; Jequier, 1987; U.S. Department of Health and Human Services, 1988). These methods are too cumbersome to use for large numbers of subjects. In population studies, ratios of weight to height are used often to estimate body mass, which correlates highly with the amount of body fat. One of the commonly used ratios is known as the body mass index (BMI), which is defined as body weight in kilograms divided by the square of height in meters (wt/ht^2) (Jequier, 1987; U.S. Department of Health and Human Services, 1988).

Reference standards have been derived from the BMI and data from the Metropolitan Life Insurance Company, where "desirable" weight is defined as that of insured persons with the longest lifespan. Although these standards actually define degree of overweight rather than obesity per se, they offer the advantage of evaluating and comparing population or subgroups within populations. Based on these approaches, it is estimated that obesity affects approximately 34 million adults, 20 to 74 years of age, in the United States, with the greatest rates observed among the poor and minority groups (U.S. Department of Health and Human Services, 1988).

Obesity is a serious public health problem (U.S. Department of Health and Human Services, 1988). It is a risk factor for coronary heart disease, high blood pressure, diabetes, and possibly some types of cancer. It also has been linked to such serious conditions as gallstones, sleep apnea, and osteoarthritis, although a causal relationship has not been established clearly.

The causes of obesity are complex and difficult to assess. Research topics that are under active investigation include influence of heredity, regulation of food intake, regulation of metabolic rate, and contribution of physical activity to the control of energy balance. This report will focus on the possible role of dietary fat in development of obesity.

Evidence that Dietary Fat Contributes to Development of Obesity

Animal Studies

Commercial stock diets fed to laboratory rodents contain carbohydrate as the major source of energy, with fat usually supplying approximately 10 to 20% of energy. When the carbohydrate content of the diet is lowered and the fat content elevated to 30 to 60% of energy, obesity generally is induced in animals (Sclafani, 1980). The degree of obesity induced by a high-fat diet is influenced by a number of factors, including type and amount of fat in the diet, length of feeding, strain, age, and gender of the animal.

One of the most pronounced variables in response to dietary fat is the genetic background of the animal. In studies employing different strains of rodents, it has been shown clearly that diet and heredity interact to determine the degree of obesity that develops in animals fed high-fat diets (Schemmel et al., 1970). For example, certain strains of rats become very obese when fed a high-fat diet but are able to maintain a decreased body fat content when fed a high-carbohydrate diet, whereas other strains of rats remain lean regardless of whether a high-fat or a high-carbohydrate diet is consumed.

Human Studies

Two general approaches have been used to evaluate the possible role of dietary fat in the development of obesity in humans. One approach has been to feed subjects meals varying in fat-to-carbohydrate ratio and measure energy intake during a single meal or for several days. These studies are seldom of sufficient length to adequately assess treatment influences on body weight or body composition. The other approach has been to record self-selected food intake and compare intake of high-fat foods with degree of obesity. Unfortunately, these studies lack the precision necessary to detect subtle differences in energy intake.

Lissner et al. (1987) prepared three diets consisting of similar foods in which fat contributed 15 to 20%, 30 to 35%, or 45 to 50% of total energy. These diets were fed to 24 women in a sequence of three 2-week periods. Subjects spontaneously consumed 2,087 $\pm$ 94, 2,352 $\pm$ 112, and 2,714 $\pm$ 105 kcal/d when fed the low-, medium-, and high-fat diets for the 2-week periods. Others also have noted greater energy intake of high-fat diets than of low-fat diets in short-term human feeding trials (Mattes et al., 1988; Tremblay et al., 1989, 1991). Results of a recent longer-term controlled-feeding trial support the findings of these short-term trials. Kendall et al. (1991) fed 13 female subjects a low-fat diet (20 to 25% of energy as fat) or a high-fat diet (35 to 40% of energy as fat) for 11 weeks. Subjects then were switched to the other diet after a 7-week washout period in the randomized crossover experiment. Overall energy intake was 12% lower when subjects consumed the low-fat diet than when the high-fat diet was consumed. Intake of the low-fat diet did increase significantly over the 11-week period, but the authors were unable to make definitive conclusions about caloric compensation because variability about the slope estimates resulted in no difference between the two slopes (low-fat diet versus high-fat diet).

Records of self-selected food intake versus the degree of obesity in humans suggest that obese subjects consume diets with a higher percentage of energy as fat than do nonobese subjects (Dreon et al., 1988; Romieu et al., 1988). This occurs, even though it is generally difficult to show that total energy intake is increased significantly in obese subjects by these approaches, probably because dietary recall and diet records lack precision in assessment of energy intake.

Results of both animal and human studies thus show that consumption of high-fat diets is associated with development and/or maintenance of obesity in at least some individuals. The next section examines some of the mechanisms that contribute to a high-fat diet-induced obesity.

Mechanisms

Control of Food Intake

Several factors contribute to the elevation in energy intake associated with consumption of high-fat diets. Fat contains approximately twice as much energy per gram as carbohydrate. Consequently, when fat replaces carbohydrate in the diet, the energy density of the diet is increased and fewer grams of food are required to yield the same total energy. Mattes et al. (1988) examined the degree of caloric compensation that occurs when subjects were provided lunches containing about 66% more or less calories than their customary midday meal for 2-week periods. Subjects compensated when fed the low-calorie lunches by adjusting nonlunch energy intake, whereas total energy intake was elevated when the high-calorie lunches were served. They concluded, as others also have noted, that humans compensate more readily for decreases than for increases in energy intake.

Orosensory properties of fats also contributed to hyperphagia. When given a choice among foods differing in fat content, rats and humans generally prefer foods containing fat (Drewnowski and Greenwood, 1983; Sclafani, 1980). The physiochemical form of the fat is another complex variable in the hyperphagic response. Lucas et al. (1989) have shown that rats consume more energy when the diet contains vegetable shortening rather than corn oil and that emulsification of corn oil increases energy intake. Interestingly, in short-term tests, rats prefer pure corn oil to the oil emulsion. This preference suggests that the hyperphagia obtained with corn oil emulsions was not caused by orosensory properties but rather by yet-to-be identified postingestive factors.

Not all dietary fats promote hyperphagia. Medium-chain triacylglycerols are composed of primarily eight- and ten-carbon fatty acids and are a valuable tool in the management of long-chain triacylglycerol malabsorption. These triacylglycerols do not promote hyperphagia or obesity (Turkankopf et al., 1982). There are a complex series of factors interacting to determine the degree of hyperphagia induced by high-fat diets.

Metabolism

The stimulation of energy intake associated with consumption of a high-fat diet obviously contributes to development of obesity, but this is not the only mechanism involved. High-fat diets also increase the efficiency with which dietary energy is converted to body energy.

Dietary fats and carbohydrates are oxidized for maintenance energy requirement with equal energetic efficiencies (Romsos and Clarke, 1980). Differences in energetic efficiency, however, are evident in the conversion of dietary fats and carbohydrates to body fat. Flatt (1978) estimated by calculation of energy costs of the metabolic pathways involved that 7% of the energy in dietary triacylglycerol is lost as heat in the conversion to body fat, whereas 28% of the energy in dietary carbohydrate is lost in the conversion to body fat. Donato and Hegsted (1985) provided a quantitative illustration of the greater efficiency of utilization of dietary fat than dietary carbohydrate for fattening in rats. They showed that one gram of dietary fat produced a body energy gain of 3.25 kcal, whereas one gram of dietary carbohydrate produced a gain of 1.1 kcal. Dietary fat was thus 2.95 times as efficient as dietary carbohydrate. Similar values had been observed earlier by others (Carew and Hill, 1964). When Donato and Hegsted (1985) assumed that dietary sucrose provided 3.94 kcal/g, the comparative energy value of dietary fat was 11.6 kcal/g, or about 128% of the expected value of 9 kcal/g. Most of the increase in body energy in their rats was in the form of body fat. Thus, the energy value of dietary sucrose should be adjusted for the energy costs associated with storing dietary carbohydrates as body fat [−28% or 2.84 kcal/g, based on estimates of Flatt (1978)]. Then the comparative energy value of fat is 8.37 kcal/g (dietary sucrose energy value for fattening of 2.84 kcal/g times 2.95). This estimate of the energy value of dietary fat for fattening (8.37 kcal/g) is identical to that obtained by adjusting the generally accepted energy value of fat (9 kcal/g) by the estimated energy costs of storing dietary triacylglycerol as body fat (−7%, based on estimates of Flatt [1978]). These calculations illustrate the differences in energetic efficiency in the conversion of dietary fats and carbohydrates to body fat.

Regardless of the high palatability of a high-fat diet or the high efficiency of dietary fat deposition as body fat, an increase in body fat content would, in a tightly coupled system, be expected to provide a signal to either lower energy intake or increase energy expenditure to maintain body weight and fat. As already mentioned, this does not always occur. Flatt (1989) has provided a metabolic-based hypothesis to explain why dietary fat promotes development of obesity.

Regulation of body weight of adults requires that body pools of protein, carbohydrate, and fat each be regulated (Abbott et al., 1988; Bray, 1987; Flatt, 1989). Maintenance of these pools is accomplished when the fuel mix oxidized has the same protein to carbohydrate to fat ratio as the diet. An increase in protein intake above that required causes a concomitant adjustment in amino acid oxidation to effectively maintain nitrogen balance. Carbohydrates stored as glycogen are limited, and the fat content of most Western diets limits conversion of dietary carbohydrates to fat in humans (Acheson et al., 1982). An increase in carbohydrate intake above that needed to maintain glycogen stores promptly increases carbohydrate oxidation, and this spares fat oxidation. Thus, body pools of protein and carbohydrate are regulated tightly. There is evidence for less control of body fat stores.

Body fat stores are large, and dietary fat intake does not promptly promote fat oxidation (Abbott et al., 1988; Schutz et al., 1989). When human subjects in a respiration chamber fed a mixed maintenance diet containing 35% of energy as fat were given an additional 987 ± 55 kcal/d as fat, neither total energy expenditure nor fat oxidation were altered over the next 36 hours (Schutz et al., 1989). These results illustrate marked differences in the acute influence of dietary fat versus dietary carbohydrate on metabolic fuel use. In summary, consumption of fat does not promote a prompt oxidation of fat, whereas consumption of carbohydrate does.

It is clearly possible for weight maintenance to be achieved when consuming high-fat diets. Consequently, fat oxidation eventually must increase to equal fat intake. The mechanisms responsible for bringing fat oxidation into balance with fat intake under these conditions are currently unknown. Flatt (1989) postulates that hyperphagia continues until the adipose tissue mass expands sufficiently to increase lipolysis, which will promote fat oxidation. The resulting obesity also would be expected to induce insulin resistance and limit carbohydrate oxidation, further promoting the relative oxidation of fat over carbohydrate.

Future Research

Much is yet to be learned about the role of dietary fat in the control of energy intake. The orosensory properties of fat, when presented in various physical forms and combinations of foods, need investigation. A better understanding of how genetic factors interact with dietary fat content to influence the degree of hyperphagia is needed also. A further challenge is to identify the critical determinants of body weight and fat control as modulated by the fat content of the diet.

16 The Role of Dietary Fat in Cancer

Summary

Epidemiologic, clinical, and experimental data, accumulated over the past 50 years, suggest that dietary fat plays a major role in the etiology of several kinds of cancer. Moreover, several biologically plausible mechanisms have been proposed to account for the tumor promoting effects of dietary fat. Available epidemiological evidence is inconsistent primarily because of the relative homogeneity of fat intake within specific populations and the poor reliability of estimates of fat intake. Animal model studies support the fat hypothesis as it relates to cancer of the breast, colon, pancreas and, to a lesser extent, the prostate gland. Preliminary evidence is now available suggesting that a randomized controlled trial of the influence of low-fat diets on breast, and possibly colon cancer, are feasible. Such trials would provide the most convincing evidence in support of the fat hypothesis. Nonetheless, several problems still remain to be resolved, including determination of the optimal ratios of saturated, monounsaturated, and polyunsaturated fatty acids in the diet and the possible role of overall caloric intake and energy expenditure.

Introduction

Although the public and medical community's awareness of the role of dietary factors in cancer development is relatively recent, that awareness has been known in the research community for almost 50 years. During the 1940s, Tannenbaum (1942), Boutwell et al. (1949), and others published a series of reports that demonstrated clearly that diet, and particularly dietary fat, could influence profoundly the development of a number of different types of cancers in rodents. Of these, one of the most clear-cut effects was detected in mammary gland cancer. Tannenbaum (1942) showed that high-fat diets accelerated the appearance and increased the incidence of mouse mammary tumors when compared with similar mice fed low-fat diets. Unfortunately, interest in diet and cancer soon receded into the background as researchers became involved in more technically challenging areas, such as viral, radiational, and chemical carcinogenesis.

Renewed interest in diet and cancer followed a report by Carroll and Khor (1975) that fat intake (or disappearance) in 39 countries around the world was correlated strongly with breast, colon, and prostate cancer mortality rates and, by the demonstration in a laboratory animal model, that dietary fat specifically stimulated the promotion stage (as opposed to the early initiation stage) of mammary carcinogenesis. Since then, a growing number of research laboratories and clinics around the world have become involved in deciphering the connection between diet and cancer (Figure 16.1).

Nature of the Evidence

Epidemiology

Evidence for dietary fat's role in breast, colon, and, to a lesser degree, ovarian, prostate, and pancreatic cancer comes from a variety of epidemiologic studies including worldwide geographic comparisons (World Health Organization, 1990), migration studies, comparison of special populations within countries, such as nuns, Mormons, and Seventh Day Adventists, with the general population (Bosland, 1986; Haenzel and Kurihara, 1968; Hill, 1987; National Research Council, 1989; Phillips, 1975; Reddy et al., 1980; Rohan and Bain, 1987; Rose et al., 1986; U.S. Department of Health and Human Services, 1989; Wynder et al., 1987), and studies of unique populations, such as the Greenland Eskimos (Dyerberg, 1982). One of the most telling comparisons has been that between the United States and Japan (Hirayama, 1978; Wynder and Hirayama, 1977). For example, although the total cancer mortality in both countries is similar (216/100,000, U.S. and 198/100,000, Japan), there are marked differences in breast (27/100,000, U.S. versus 6.7/100,000, Japan), colon (males) (24/100,000, U.S. versus 18/100,000, Japan), and prostate (23/100,000, U.S. versus 5/100,000, Japan) cancer mortality rates (Boring et al., 1991). Moreover, Japan is similar to the United States in terms of literacy and standard of

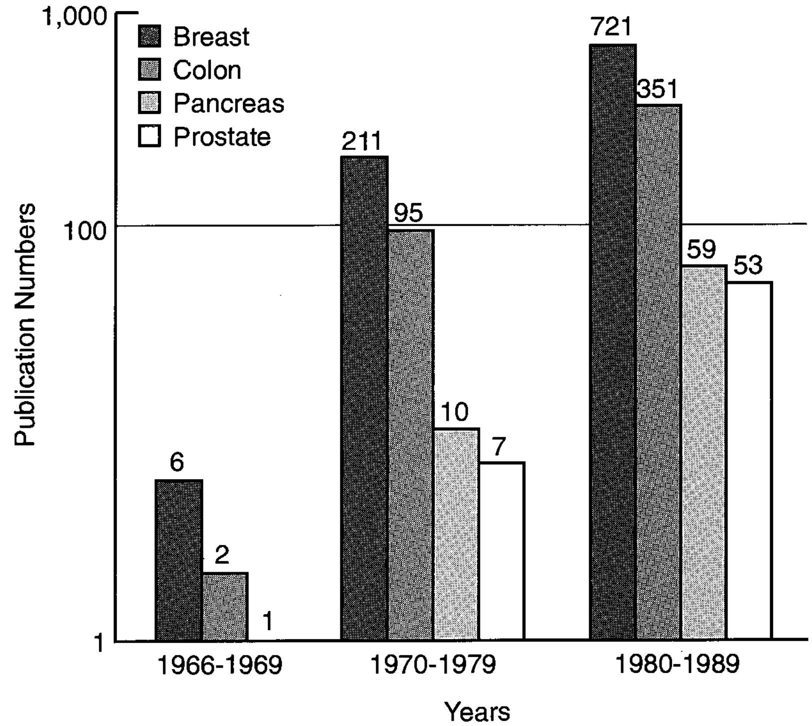


Figure 16.1. **Numbers of publications on dietary fat and cancer from 1966 to 1989 (Data from U.S. Department of Health and Human Services, National Library of Medicine, 1990.)**

living but differs in that Japanese currently consume on average one-half the amount of fat and, 20 years ago, consumed one-quarter of the amount of fat as Americans (Hirayama, 1978). Interestingly, with regard to breast cancer, the effect of dietary fat is most evident in the postmenopausal rather than the premenopausal age groups (Hirayama, 1978), suggesting that in humans, as well as in rodents, dietary fat exerts its effects on the later (promoting) stages of cancer development.

The weakest link in the epidemiological evidence has been in case/control studies and prospective cohort studies. In a large cohort study (Willett et al., 1987), 89,538 U.S. nurses were followed over time to determine whether those who consumed more fat developed breast cancer at a greater rate than did those who consumed less fat. No difference was found between nurses who consumed 32% of calories as fat (lowest intake) and those who consumed 44% of calories as fat (highest intake). One possible reason for the negative result recently was brought to light by Toniolo et al. (1989). In a case/control study conducted in Italy, where the difference between the upper and lower limits of fat intake is greater than in the United States (26% to 46%), Toniolo et al. (1989) found that breast cancer was less common in women who consumed 26% fat than in those who consumed 46% of calories as fat. Hence, the protective effect of fat seems to occur somewhere under 30% of total calories—an intake pattern that is rare in the United States, where fat intake is uniformly high. Interestingly, Willett et al. (1990) found, in the same cohort of women, that colon cancer incidence was associated with the consumption of total and animal, but not vegetable, fats and concluded that breast and colon cancer, therefore, had different relations to fat intake. It must be borne in mind, however, that epidemiological studies, no matter how well designed and implemented, can show only association not causation (Burkitt, 1970). To demonstrate causation convincingly, controlled laboratory experiments and prospective clinical trials must be conducted.

Experimental Studies

Fat and Primary Tumor Development

There are presently well over 40 independent experimental animal studies spanning half a century that indicate high-fat intake promotes mammary, colon, pancreatic, and prostate cancer (Reddy and

Cohen, 1986: Roebuck et al., 1989). The greatest number of these studies have been in mammary tumor models. These studies have shown not only that the fat effect is exerted primarily at the promotion stage of carcinogenesis but that, at least in breast cancer, a threshold seems to exist somewhere between 25 and 30% fat as calories (Cohen et al., 1986a), which is in keeping with the Toniolo study (1989). Of particular interest is the fact that the type of fat is as important as the amount (Figure 16.2). For example, high-fat diets containing oils rich in polyunsaturated fatty acids (e.g., safflower, sunflower, and corn) promote tumorigenesis (Carroll and Braden, 1985; Cohen et al, 1986b) to a significantly greater extent than do oils rich in monounsaturates (e.g., olive oil) (Cohen et al., 1986b), medium-chain length saturated fatty acids (Cohen and Thompson, 1987), and oils (e.g., fish oil) rich in a class of long-chain polyunsaturated fatty acids known as ω-3 fatty acids (Kaizer et al., 1989; Karmali et al., 1984). The olive oil data have provided new insight into the fact that Mediterranean countries, such as Greece, Italy, and Spain, which have an olive oil-based diet, have lower breast and colon cancer rates (Figure 16.3) than do the United States and northern European countries, despite the fact that their fat intake is on average above 30% of total calories (LaVecchia et al., 1988). The high intake of monounsaturated fatty acids, characteristic of these countries, may exert a protective effect with regard to breast and colon cancer. Hence, both the amount and the type of dietary fat play an important role in determining the role of fat in tumorigenesis.

Fat and Metastases

The vast majority of experimental studies have focused on what are called primary tumors, that is, those tumors that arise at a particular organ site. The most dangerous stage of carcinogenesis is, however, the progression stage, namely the point at which tumor cells leave the primary tumor and disseminate or metastasize via the lymphatic system and blood to distant sites such as bone, liver, and brain. Death usually ensues from such metastases, not from the primary tumor, which, in many cases, can be excised surgically. Whereas good models of the metastatic process are few and far between, some studies have been conducted with metastasizing mammary tumors. Katz and Boylan (1989), for example, found that a high-fat diet stimulates metastases from an implanted tumor fragment to the lung, but this stimulation occurred only in retired breeder (i.e., postmenopausal)

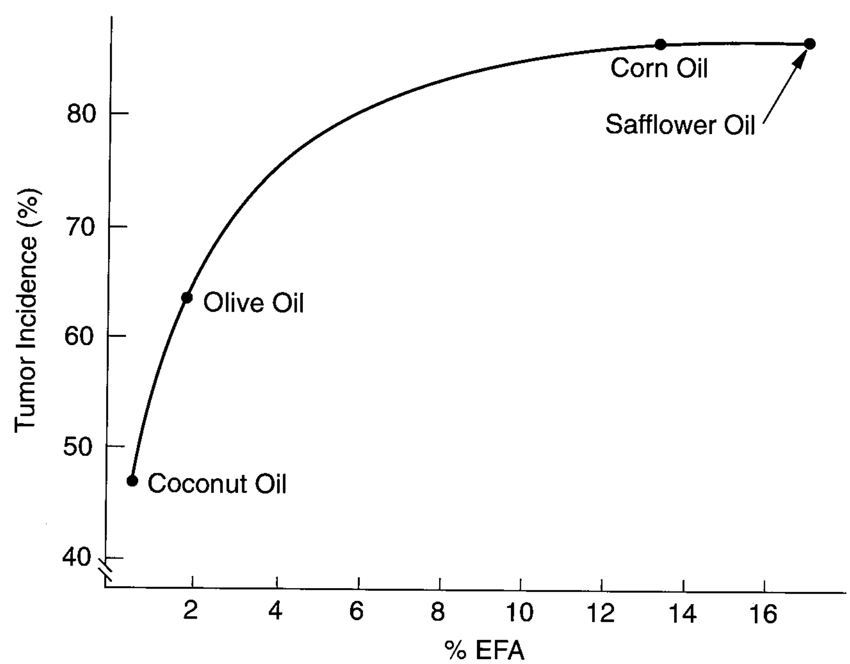


Figure 16.2. Effect of essential fatty acid (EFA) on *N*-nitrosomethylurea-induced mammary tumors. F-344 female rats were fed a 23% fat diet (Adapted from Cohen et al., 1986b).

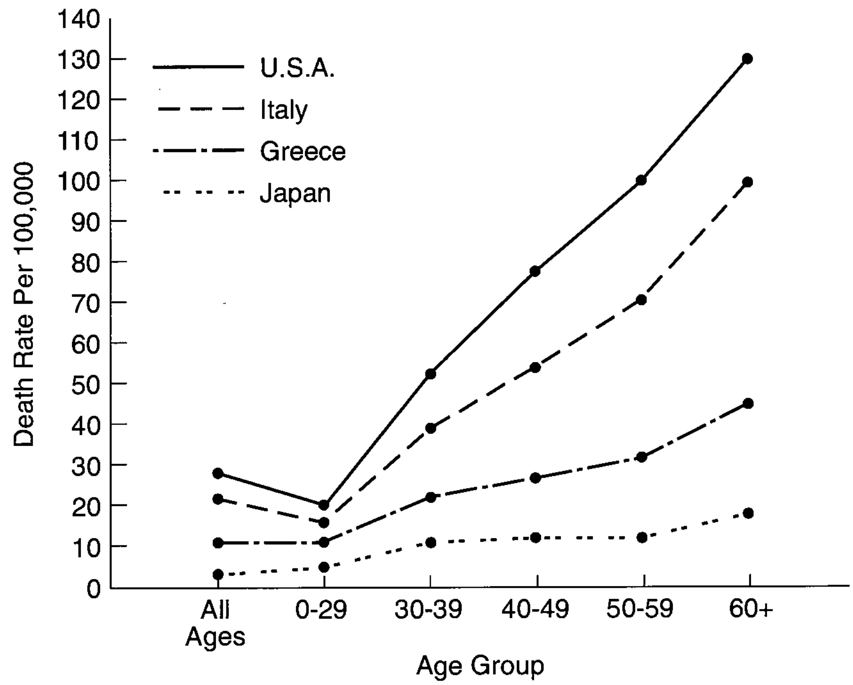


Figure 16.3. Breast cancer death rates by age group (1965 to 1969) (Logan, 1975).

not in young (premenopausal) rats. In addition, Katz and Boylan (1987) and Hubbard et al. (1988) have shown in a different model that diets high in polyunsaturated fatty acids stimulate metastases to a greater extent than did diets low in polyunsaturated fatty acids. Recently Rose et al. (1991) reported that human mammary tumor cells implanted in female nude mice metastasized to the lung to a significantly lesser degree in mice fed low fat (5% corn oil) compared to high fat (23% corn oil) diets. Hence, the concordance between the epidemiological and experimental evidence is high, particularly in the case of breast cancer both in regard to the promotion (growth of primary) and progression (metastasis) stages of carcinogenesis.

Fat Versus Calories

A number of experimental studies, also dating back to the early 1900s, have shown that decreased caloric intake inhibits cancer development (Albanes, 1987; Kritchevsky et al., 1989). Because of the availability of suitable animal models, a major part of the recent studies of dietary fat have focused on mammary carcinogenesis. In brief, feeding animals 25% or less of ad libitum caloric intake results in significant tumor inhibition. In the extreme case of the N-nitrosomethylurea-induced mammary tumor, 25% caloric restriction resulted in 90% tumor inhibition when compared with ad libitum-fed controls (Cohen et al., 1988). A few reports have claimed that 10% restriction is sufficient to impede tumor development, but these results have not been reproduced as yet (Klurfeld et al., 1989). Because of these observations, some have suggested that the fat effect is essentially a caloric effect (Kritchevsky et al., 1989). In summary, whereas there can be no doubt that caloric restriction in experimental animals results in diminished tumor development, it remains unclear whether this is the result of a systemic effect on overall animal growth or of selective physiological, hormonal, or neurochemical effects, which result in inhibition of tumor development (Welsch, 1989). A caloric effect in humans remains to be proven.

Mechanisms

The mechanisms by which high-fat diets stimulate cancer development are only remotely understood. Early studies by Cohen (1981) suggested that, in the case of mammary cancer, the fat effect was mediated by the polypeptide hormone prolactin. This hypothesis was based on the fact that prolactin is a well-known promoter substance in murine and, to a lesser extent, human breast cancer and that high-fat diets increased circulating concentrations of prolactin. When tested in other laboratories, inconsistent results were

Table 16.1. Research on the mechanisms by which high-fat diets may stimulate mammary cancer development

Mechanism	Mediator	Reference
Endocrine	Prolactin	Cohen, 1981
	Estrogens	Prentice et al., 1990
	Free estrogen, SHBG	Jones et al., 1987
	Bioactive prolactin	Rose et al., 1987
Autocrine	Prostaglandins	Karmali, 1983
Immune	NK cells	Plescia et al., 1975
	NK cells	Erickson, 1986
Oncogene activities	*Ras* gene	Tsai et al., 1990
Gut bacteria	Dietary precursors converted to estrogen-like compounds	Adlercreutz, 1984
	Dietary precursors converted to estrogen-like compounds	Goldin et al., 1982
Membrane structure	Prolactin receptor	Cave and Jurkowski, 1984
Lipid peroxides	Cholesterol epoxide	Gruenke et al., 1987

obtained. Hence, at the present time, the prolactin hypothesis remains a matter of controversy (Welsch, 1989). Other mechanisms are outlined in Table 16.1. With regard to colon cancer, increased bile acid production attendant upon ingestion of a high-fat diet, together with alterations in gut bacteria result in increased conversion of primary bile acids to secondary bile acids. The possibility that secondary bile acids act to promote preneoplastic lesions in colonic villi has been proposed as a plausible but yet unproven mechanism by which dietary fat enhances colon tumorigenesis (Hill, 1987; Reddy and Cohen, 1986) (Figure 16.4).

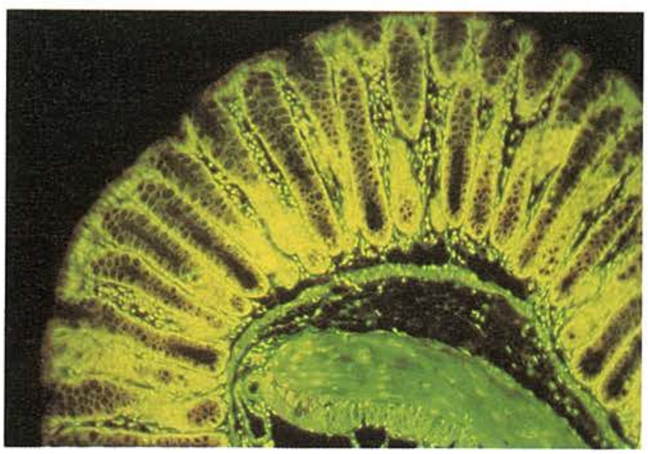


Figure 16.4. A section of normal rat colon depicting the crypts and villi of the colon. The lumen is to the left and the muscularis mucosa to the right. The villi project out into the lumen where they come into contact with the contents of the colon. Colon cancer originates, for the most part, at the tips of the villi. Stained with fluorescein-isothiocyanate (Absorption max 495 nm; emission max 515 nm). The photomicrograph was taken under UV illumination at approximately 400 x magnification. Photograph courtesy of Leonard A. Cohen, American Health Foundation, Valhalla, New York.

A great deal of attention has been paid to the possible role of prostaglandins in the fat effect. This is because prostaglandins are biologically active derivatives of the essential fatty acid linoleic acid ($C_{18:2}$, ω-6) (linoleic acid-rich oils stimulate mammary tumorigenesis to the greatest extent), and because numerous tumor types overproduce prostaglandins (Karmali, 1983). The entire eicosanoid family of prostaglandins and lipoxygenase products has been the subject of intense research interest because alterations in competing pathways leading to often antagonistic end products could help provide a framework for understanding the nonpromoting effects of olive and fish oils, which are rich in oleic ($C_{18:1}$, ω-9) and eicosopentaenoic acids ($C_{22:5}$, ω-3), as well as the tumor-promoting effects of conventional oils rich in linoleic acid ($C_{18:2}$, ω-6) (Sinclair, 1982).

Intervention Trials

Clearly, the ultimate test of the fat hypothesis is a randomized prospective dietary intervention trial. Such a trial, however, is unlikely ever to be carried out because it would involve thousands of subjects who would have to be fed specific diets and watched over a period of at least five to 10 years. This unlikelihood is because, out of every 1,000 healthy individuals drawn at random from the population, roughly only one will present with cancer annually. A more realistic way to test the fat hypothesis was proposed originally by Wynder and Cohen (1982) and involved dietary intervention in postmenopausal women who already have cancer. As many as one-half of these patients will have a recurrence within two years if there is lymph node involvement. The National Cancer Institute has underwritten several intervention trials, including the now defunct Women's Health Trial, which attempted to study the effects of low-fat intake on healthy women with a high risk of breast cancer based on their family history and the presence of benign breast disease (Self et al., 1988). This trial was terminated because of a variety of logistic, scientific, and financial reasons. For one, the projected cost had risen to $\$100 \times 10^6$!

A revised form of the Women's Health Trial was approved recently and again turned down (Marshall, 1990). The new trial would have involved 24,000 healthy postmenopausal women from 12 regions of the United States. Forty percent were to consume a low-fat diet (20% of calories); the remaining 60% were to consume their customary high-fat (38% of calories) diet. The study was expected to take 15 years and cost over $100 million. It differed from the previous trial in that breast and colon cancer and heart disease were to be assessed. The trial was disapproved by the Division of Cancer Prevention and Control Board of Scientific Counselors on the grounds of cost, doubts about compliance, and ethical considerations.

Currently, a less grandiose multi-center trial called the Women's Intervention Nutrition Study is underway, involving a number of centers in California, Masschusetts, New York, Ohio, and Texas in which breast cancer patients are fed a low-fat diet after surgery and monitored for several biochemical markers (serum estrogens and lipids) of breast disease at later time points (National Cancer Institute, 1988). Ultimately, the goal is to determine whether or not placing postmenopausal breast cancer patients a low-fat diet after surgery will decrease the rate of cancer recurrence (metastasis).

Dietary Recommendations

Based on the foregoing, it can be seen that an abundance of evidence has accumulated over the past 40 years to suggest that dietary fat is an important contributor to risk of breast and colon and, to a lesser extent, ovarian, prostate, and pancreatic cancer. The role of fat in lung cancer is the least well substantiated. Because breast and colon cancer account for 31% of all female cancer deaths and almost 20% of all male and female cancer deaths, or, put in more meaningful terms, there will be 44,500 estimated deaths from breast cancer and 53,000 deaths from colon cancer in 1991 in the United States (Boring et al., 1991), even a small reduction in that number, for example 10%, would result in the saving of almost 10,000 lives. For this reason, some have claimed that dietary recommendations to the public to decrease fat intake from the current 38 to 40% of total calories to 30% of calories is the correct and responsible position for governmental and private health agencies to take (National Research Council, 1989; U.S. Department of Health and Human Services, 1989). Opponents claim that until ironclad proof is obtained, i.e., successful completion of a clinical trial, no general recommendations should be made (Harper, 1980). Other factors also must be considered. There is the question of whether a decrease from 40 to 30%, as suggested by the National Research Council (1989), is enough to afford protection. Evidence discussed earlier suggests that it may be necessary to decrease fat intake to below 30% of total calories. In addition, it may be necessary to factor the role of fat type into the equation, that is, to assess which blend of different fats is optimal for cancer prevention (Carroll and Khor, 1975; Cohen et al., 1986b; Hursting et al., 1990). It must be understood that successful completion of a large-scale clinical trial will not occur until well into the 1990s, if at all (Boyd, 1990; Zelen, 1988). Hence, the dilemma is that a decision has to be made based on compelling, yet incomplete, evidence (Byers, 1988; The Cancer Letter, 1990). In light of the aforementioned, an overall reduction of fat intake to 30% or below of total calories and a shift towards a more balanced (1:1:1) ratio of saturated to monounsaturated to polyunsaturated fatty acids seems a sensible interim recommendation to decrease the risk of nutrition-related cancers.

17 The Role of Dietary Fat in Diabetes and Kidney Disease

Summary

The incidence of non-insulin-dependent diabetes mellitus is greater in obese than in nonobese people. Thus, this type of diabetes is associated with dietary fat through the association of dietary fat with obesity. There is also evidence for a direct relationship between high fat diets and diabetes. Dietary fat, through a possible effect on blood lipids, may also be a risk factor for kidney disease.

Diabetes

Introduction

Diabetes mellitus can be subdivided into two types. Type I or insulin-dependent diabetes mellitus (IDDM) typically develops in childhood. It is precipitated by a total failure of the pancreas to secrete insulin. Thus, individuals with this type of diabetes are absolutely dependent on daily insulin administration. This type of diabetes is present in about 1% of individuals in the United States. The second and more common type of diabetes is Type II or non-insulin-dependent diabetes (NIDDM). NIDDM generally develops in later life, most often in individuals who are overweight. It is characterized by a relative rather than absolute insulin deficiency. Although an adequate amount of insulin seems present in these individuals, especially in the earlier stages of NIDDM, they seem resistant to its action. This form of diabetes is present in approximately 18% of individuals over the age of 45 in the United States, and its prevalence has been increasing steadily. In addition, the occurrence of NIDDM is increasing at more significant rates in several populations, such as American Indian, Mexican Americans, and several Pacific Island populations after they have transferred to an urban or westernized lifestyle.

NIDDM is associated most commonly with obesity. When prospective studies have been available, they have shown unanimously that the incidence and rate of development of the disease is related to the degree of obesity. Most of the morbidity and mortality associated with NIDDM is caused by long-term vascular complications, the most prevalent of which is atherosclerotic cardiovascular disease. Individuals with NIDDM as well as those with IDDM have an increased prevalence of myocardial infarctions, congestive heart failure, and peripheral vascular disease.

Diet and Diabetes

Because of the apparent increase of the frequency of NIDDM with westernization and because of its relationship to obesity, diet has long been suspected to play a role in its development. As early as 1875, French physicians described diabetes as being associated with obesity and noted that its rates declined during periods of food shortage. It is difficult, however, to separate the roles of dietary fat from total caloric intake in the development of diabetes.

Obesity has been demonstrated to be a strong predictor for the development of diabetes in many populations. Thus, dietary fat is related inevitably to the development of NIDDM, because obesity is induced by hypercaloric diets and hypercaloric diets are associated almost universally with increased dietary fat. That caloric excess may have an etiologic role in the diabetes also is supported by clinical studies on the role of diet in ameliorating diabetes. Caloric restriction, generally accomplished by decreasing dietary fat intake, improves glucose control and can sometimes induce a remission in non-insulin-dependent diabetics. In addition, two longitudinal trials have documented a positive effect of dietary fat restriction on the progression from impaired glucose tolerance, a condition of mild elevations in blood glucose, to overt diabetes.

Other clues concerning the role of diet and the pathogenesis of diabetes come from certain populations with an unusually high prevalence of diabetes. There have been studies of a number of populations that have undergone rapid changes in their way of life, including Yemenite Jews, Australian Aborigines, several Pacific Island populations, and the Pima Indians of Arizona. The higher prevalence of diabetes associated with the conversion to urban or westernized environments in all of these cases has been accompanied by a change in dietary patterns from diets characterized by the consumption of local fruits and vegetables, which usually are high in fiber and carbohydrate contents, to diets containing large quantities of fat. In some Pacific Island communities, striking differences have been shown in the incidence of diabetes between particular groups still living in their traditional environment and their relatives who have moved to an urban environment. The prevalence of diabetes among Japanese who have migrated to the United States is higher than that among Japanese in Japan. A dietary survey has shown that the number of calories consumed in the two locations is the same, but Japanese Americans consume approximately twice as much fat as their counterparts in Japan.

The difficulties of interpreting interpopulation comparisons and interpreting associations based on cross-sectional data may be avoided by prospective studies within populations where the risk of developing diabetes has been determined directly in relation to dietary intake before the development of the disease. There have been only a few prospective studies, however, to determine whether or not diet plays a role in the development of diabetes. An intervention trial in Sweden that restricted dietary fat and decreased calories in overweight individuals resulted in a decrease in the 10-year incidence of diabetes. A prospective study analyzing the diet of Pima Indian women has suggested an association between the incidence of diabetes and both fat and total calorie intake. On the other hand, a prospective study of the development of diabetes in Israel showed no effect of diet or its components on the incidence of diabetes. A recent short-term intervention study, in which a diet high in dietary fat was compared with one of equal calories but high in complex carbohydrates and traditional foods, has shown that the high-fat diet was associated in all individuals with higher blood glucose concentrations.

Dietary Recommendations

Although more prospective studies are needed to define the relationship between dietary fat in the development of diabetes, a diet restricted in calories with a high proportion of complex carbohydrate and a restricted amount of saturated fat and cholesterol is recommended, both for the prevention of the development of diabetes and for the therapy of individuals with this disease. A low-fat diet, which facilitates calorie restriction, will prevent the development of obesity, a factor that has been demonstrated conclusively to increase the incidence of diabetes. If diabetes develops, a weight restriction regimen, again most easily accomplished by lowering the fat in the diet, will almost always improve glucose control. Finally, because diabetics are at greater risk for cardiovascular disease, both because of their diabetes and because of the increased prevalence of hypertension and dyslipidemia that often accompanies their diabetes, a low-fat, low-cholesterol diet is highly recommended as a prevention strategy for this potentially lethal complication.

Kidney Disease

Association Between Kidney Disease and Disorders of Lipid Metabolism

Interest in a possible link between fats and renal disease began with early observations of lipid droplets in the glomeruli of individuals with renal disease. It generally has been assumed that many of the changes in plasma lipoproteins associated with renal disease have been sequelae of the renal dysfunction. Individuals on dialysis generally have disorders in concentrations of blood cholesterol and triacylglycerols. The mechanism of these changes has not been established, although decreased concentrations of lipoprotein lipase activity, an enzyme that catalyzes hydrolysis of blood triacylglycerols, have been observed in patients with kidney failure. In individuals with nephrotic syndrome or with gross proteinuria, plasma cholesterol and triacylglycerol concentrations can be elevated significantly. The mechanism for these changes also is not understood well. One early metabolic study suggested that the metabolism of blood cholesterol was normal in individuals with nephrotic syndrome, but animal studies have implied that the lipoprotein elevations might be a reflection of changes in liver function induced as a result of the urinary protein loss.

Relationship to Dietary Protein

Recent attention has focused on the relationship between protein intake and kidney disease, especially in diabetics. Interest was stimulated by studies on animals that defined a sequence of events in the decline of kidney function induced by diabetes. It was shown that this sequence was accelerated by diets high in protein and could be retarded by a protein-restricted diet. These observations have been expanded subsequently to human studies, where several small trials have suggested that limiting dietary protein can aid in the prevention or retardation of the renal complication in diabetics. The use of a protein-restricted diet, however, raises the question of how to design these diets and their possible long-term consequences. A larger multicenter trial is now underway to carefully define the effects of dietary protein in the development of diabetic renal disease.

Possible Role of Dietary Fat

More recently, renewed interest in a possible association between dietary fat and renal disease has been spurred by animal studies that have suggested that high concentrations of blood fats are predictive of the development of renal disease and that therapy to decrease blood lipid concentration decreases the progression of albuminuria and glomerulosclerosis. Although there is little information in humans concerning the possibility that diet and blood lipids may play a causative role in the development of renal disease, high blood cholesterol recently has been shown to be an independent risk factor for kidney disease in Type I diabetics. The mechanism for a possible causative role of lipoproteins in the development of renal disease is totally unknown at this time. One could postulate that an atherosclerotic process can occur in the glomerulus, that renal dynamics are altered by elevated plasma lipid concentrations, or that plasma lipids result in changes in the fluid structure of the membrane of the glomerulus and, therefore, its function. Because intake of dietary fat and cholesterol is related directly to concentrations of circulating lipids, more research is needed to clarify this possible link between the composition of fat in the diet and kidney disease.

18 The Role of Dietary Fat in Infections and Immunity

Summary

Although it has been demonstrated for some time that components in the diet can influence immunity, only in the last 15 years has fat been shown to play a role. Relative to the number of studies that have focused on the effect of fatty acids in culture on cells of the immune system, very few studies have used a dietary approach. Nevertheless, the studies generally tend to show that a deficiency in essential fatty acid(s) decreases host immune status as well as T-cell, B-cell, and macrophage function. Likewise, high concentrations of fat also tend to suppress those same immune functions. In autoimmune diseases, such as systemic lupus erythematosus and experimental allergic encephalomyelitis, those fatty acids have a beneficial effect in alleviating the severity of the pathological process. Marine fish oils, which also have been demonstrated to selectively influence responses of the immune system, such as the killing of tumor cells, also may have a beneficial effect in host defense. Possible means by which dietary fats may influence the immune system include alteration of cell membrane structure and function and modulation of fatty acid metabolites, the eicosanoids. Eicosanoids have a regulatory influence on many systems of the body, including the immune system.

Introduction

The idea that diet could influence immunity has been recognized for some time, but only in the last two decades has it been shown that dietary fat could influence components of the immune system. Although a number of reports indicate the influence of fatty acids and lipids in culture on cells of the immune system (Erickson, 1986; Johnston, 1985; Meade and Mertin, 1978; Trail and Wick, 1984), very few have focused on dietary fat. The aim of this chapter is to review dietary fat influences on immune response as well as on disease involving the immune system. From this, possible mechanisms by which dietary fat may influence immunity will be discussed. To put this in context, basic immunological terms first will be defined.

Immunity originally referred to the relative resistance to bacteria. Immune responses, however, are not always beneficial nor are they confined to resistance of infection. The immunological system is not only designed to perform a defense function but it is also concerned with homeostasis and surveillance. Thus, the immune system in its most broad sense consists of all the physiological mechanisms that allow an individual or animal to recognize something that is foreign, to neutralize it, and to eliminate or catabolize it. This immune response may be divided into a nonspecific and a specific component. An example of the nonspecific immune response is inflammation, the body's reaction to an injury. The specific immune system can be divided into two major branches, cellular and humoral. Both responses are essential to the defense against foreign substances; one response, however, may be favored. Cellular immunity resides in lymphocytes, which migrate through the thymus and are referred to as T-cells. Those cells are particularly effective against fungi, parasites, intracellular viral infections, and tumor cells. In contrast, the humoral immune system is mediated principally by a protein or antibody, which is produced by lymphocytes known as B-cells. The production of antibodies by B-cells requires cooperation and help from T-cells in most cases. In addition, the immune system depends on other accessory cells, such as macrophages. The foreign entities that the immune system recognizes are antigens or macromolecules, such as foreign proteins, nucleic acids, and carbohydrates. Mediators and cytokines may be released from T-cells, B-cells, and macrophages; they are able to regulate or modulate a number of immunological activities.

Dietary Fat and Immune Response

Alteration of dietary fat can result in alteration of the fatty acid composition of the cell itself. For example, diets varying in either the concentrations or saturation of fat changed the fatty acid composition of whole lymphocytes (Erickson et al., 1983; Marshall and Johnston, 1983; Meade et al., 1978). Moreover, the composition of the cell membrane can be modified in animals fed diets with high concentrations of fat. The magnitude of the change and the specific fatty acids altered will vary with the cell populations and the dietary fat.

Diets either deficient in essential fatty acids or containing high concentrations of fat can influence general host immune status. Not only can dietary fat influence immune response in the mature animals, but select fatty acids may be important in the prenatal and postnatal period as an influence on parameters of immune status (Erickson et al., 1980). The exact effects may depend upon the duration of feeding and the organs examined. In addition to the influence on immune status, several types of studies have shown that dietary fat may help regulate immune responses through its influences on T-cells. This has been shown by modulation of functions such as decreased rejection of foreign tissue grafts (DeWille et al., 1981; Mertin and Hunt, 1976; Thomas and Erickson, 1985a), proliferation of lymphocytes in response to a foreign cell (Erickson et al., 1983), and change in the ability of the lymphocyte to kill a foreign tumor cell (cytolysis). For example, an increase in dietary fat to 20% by weight of diet dry matter was associated with a decrease in anti-tumor cell-mediated immune response. That function was inversely proportional to the amount of dietary fat. The effect of dietary fat change seemed to be directly on the T-cell, because there were no differences in (1) the number of T-cells or their subsets or (2) in alteration in susceptibility of the tumor cell to being killed (Thomas and Erickson, 1985b). Other measures of T-cell function in the host, such as rejection of a foreign tissue graft and delayed type hypersensitivity, which is an immunological reaction similar to that after contact with poison ivy, have been shown to be influenced by dietary fat. In those types of responses and others, high fat concentration (20% by dry weight) could be associated with the suppressed response. Because concentrations of linoleic acid in the lymphocyte changed in an inverse relationship to lymphocyte function, we, as well as others (Erickson, 1986; Mertin and Mertin, 1988) have concluded that linoleic acid may play an important role in the modulation of T-cell responses.

Depending on how B-cell function was measured, dietary fat did or did not have an influence on immune function. Essential fatty acid deficiency either increases specific antibody production or depresses it, depending on how the foreign material or antigens entered the body (Boissonneault and Johnston, 1984; DeWille et al., 1979). Dietary fat also may affect serum immunoglobulin concentrations as well as the degree of antibody response to a defined antigen. For example, high concentrations of dietary polyunsaturated fat suppressed the production of specific antibodies as long as a minimal amount of essential fatty acids were available. From these and other studies, we may conclude that dietary fat does not affect the total number of B-cells but rather the number of cells responding to an antigen and the concentration of antibody produced (Erickson et al., 1986).

Macrophages are a highly diverse population of cells capable of executing or modifying a number of important biological functions including an immune response. One major function of the macrophage is to protect the host from infectious agents or their products. Dietary fat may influence some parameters of macrophage function but have no effect on others. For example, the capacity of macrophages to kill melanoma tumor cells from mice fed diets with 8% and 20% safflower oil was less than for mice fed diets containing coconut oil (Erickson et al., 1989). The relationship of dietary fat to prostaglandin production and macrophage activity is an important one, because prostaglandin E_2 plays a very pivotal role in the shut-off of many macrophage functions, such as the capacity to kill tumor cells. Prostaglandin E_2 is a metabolite of a specific fatty acid, arachidonic acid, and its concentration may be changed by altering dietary fat composition and concentration. Phagocytosis, the ability to take up foreign material, is accompanied by formation of prostaglandins by the macrophage. Prostaglandins produced by the macrophage not only autoregulate its activity but may influence the functional activities of a number of other cells. Such is the case in an inflammatory response. Thus, a whole family of eicosanoids, which includes prostaglandins, besides being considered as pro-inflammatory, are also strong suppressives of several lymphocyte functions.

Recently, considerable attention has focused on how dietary manipulation of fatty acids, particularly those found in marine oils, influence immune response. Marine fish oils contain high ratios of the ω-3 fatty acids. Studies suggest that dietary manipulation of fatty acids can alter activation of tumoricidal capacity of macrophages, both dependent and independent of changes in prostaglandin synthesis (Somers et al., 1989). In addition, macrophages from animals fed diets high in ω-3 fatty acids, such as those found in fish oils, produced more tumor necrosis factor α or cachectin than did macrophages from animals fed diets high in ω-6 fatty acids, such as in safflower oil. Tumor necrosis factor α, a cytokine, not only plays a role in causing destruction of tumor but also has a multitude of biological activities including stimulation of fibroblast growth, collagenase production, and bone resorption as well as inhibiting a lipid metabolism enzyme called lipoprotein lipase (Beutler and Cerami, 1986).

The latter effect on lipoprotein lipase may be associated with the wasting disease found in cancer. This change in the ability of macrophages to kill tumor cells and to produce soluble mediators seems to be regulated by prostaglandin E_2. In a similar fashion, suppression of macrophage activity induced by a high fat diet (20% corn oil) may account for a lesser resistance to a lethal bacteria called *Listeria* (Shinomiya et al., 1988).

Very few studies of lipids and immune response in humans have been published. When normal human subjects were fed supplements of safflower or olive oil, cell-mediated immune response was inhibited (Utermohlen et al., 1980). This inhibition was less in subjects fed safflower oil than olive oil. In contrast, fatty acids added to cultures of human lymphocytes generally have shown that polyunsaturated fatty acids inhibited lymphocyte stimulation, whereas saturated fatty acids had little effect. The problem, however, of interpretation of in vitro fatty acid effects is that the complexity of cell interactions cannot be controlled. Besides a possible direct effect of fat on immune function, it is possible that fatty acids indirectly may have an influence mediated through other routes, such as changes in hormonal status, e.g., corticosteroids, insulin, or thyroxine, in such a way as to modify lymphocyte reactivity.

Dietary Fat and Immune-Associated Diseases

Systemic lupus erythematosus is an autoimmune disease of unknown cause that leads to inflammation in several organs. It has the potential of severe complications and a significant incidence of mortality; the most common cause of death is renal involvement. Current therapy is often inadequate; thus, less toxic therapies are necessary. Several strains of inbred mice serve as models for that disease because of their many pathologic similarities to the human disease (Smith and Steinberg, 1983). Dietary fat has been shown to have a pronounced influence on the spontaneous development of autoimmune disease. Animals fed a high amount of saturated fat or a moderate amount of unsaturated fat had more severe kidney disease and died earlier than did mice fed a low-fat diet. Likewise, dietary fish oil lessened the progression of autoimmune kidney disease and mortality, but it may aggravate inflammation of the blood vessels (Robinson et al., 1985; 1986). Other immune reactions, such as the production of immunoglobulins E and G, may be increased in animals fed fish oils. In addition, diets high in marine fish oils have been shown to prolong bleeding times, protect against thrombosis, and alter the pathology of rheumatoid and collagen-induced arthritis (Prickett et al., 1981). Diets containing ω-3 fatty acid generally are considered to be anti-inflammatory because of unique biological properties of metabolites found selectively in marine fish oils. Additionally, fish oil diets have been shown to decrease the growth of tumors known to be sensitive to linoleic acid. One possible explanation for dietary fish oil effects on tumorigenesis is altered regulation of lymphocyte and macrophage cytolytic ability.

Experimental allergic encephalomyelitis, a cell-mediated immune disease of the central nervous system, has been used to study the influence of dietary fats on the course of autoimmunity (Gurr, 1983). Feeding of an essential fatty acid-deficient diet or one supplemented with linoleic acid was associated with a lessening of the severity of overt clinical signs of disease. The protective effect of linoleic acid is most likely mediated by immune suppression (Meade et al., 1978).

Multiple sclerosis is a human disease characterized by degeneration of the myelin sheath of nerves with an associated change in lipids. Autoimmune mechanisms may play a role in the degenerative process (Millar et al., 1973). Patients given supplements of sunflower seed oil had relapses that were less frequent and severe and shorter in duration than patients receiving olive oil. In addition, treatment with low-fat diets (less than 20 g per day) before severe disability developed improved prognosis (Swank and Grimsgaard, 1988).

Possible Mechanisms

There are several possible mechanisms by which dietary fat may influence immune response, but two seem to be the principal mechanisms and those have considerable overlap. First, dietary fat may change cell membrane structure and function. Changes in the composition of the membrane, and thus the lipid environment, may change a number of processes in immune response. Another possible mechanism by which dietary fat may influence immunity is through modulation of eicosanoid synthesis. The production of eicosanoids, such as prostaglandins, can change with dietary fat, and those compounds generally have been shown to have a suppressive effect on a number of activities in T- and B-cells as well as macrophages. Modulation of gene expression is a third but yet unexplored possible mechanism by which dietary fat may influence immune response. Changes associated with expression of gene products, such as tumor necrosis factor α by prostaglandins, already have been demonstrated (Kunkel et al., 1988).

Conclusions

We are just beginning to understand the role that dietary fat can play in immunity. Evidence now indicates that dietary fat can modulate select immune responses. This may be important as the immune system plays a major role in homeostasis, defense, and a number of pathological processes. Generally, dietary fat-associated changes in immune response have been demonstrated by using high concentrations of one type of fat. Because diets consumed by humans usually contain a blend of fats, it will be important to assess the effects of varying ratios of those blends on immune function. Most studies published to date have focused on dietary fat and basic immune function, and it is important to understand the mechanisms. Future studies, however, need to now also focus on dietary fat and immune response as it relates to processes such as infection.

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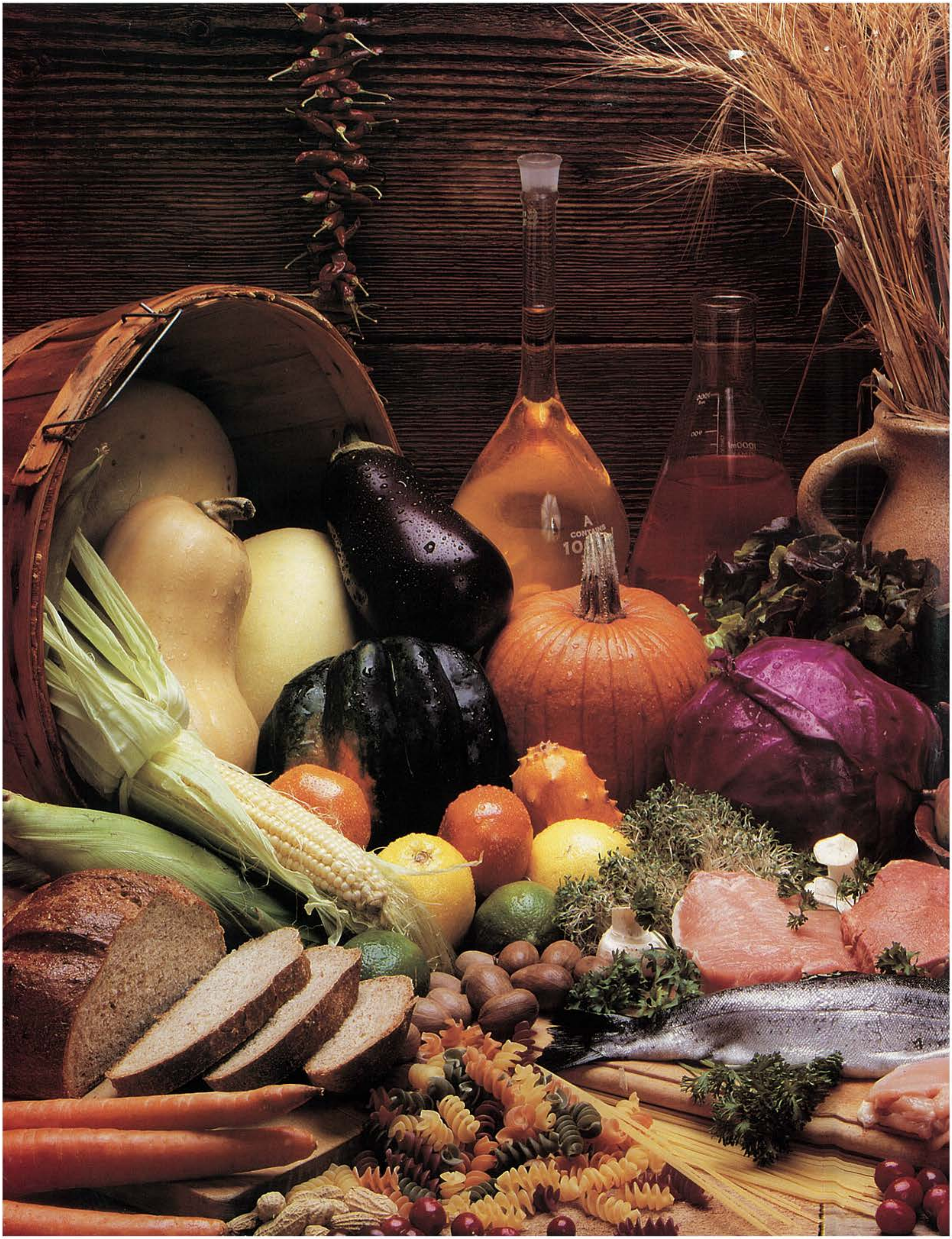
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