FATTY ACIDS IN FOODS
and their
HEALTH IMPLICATIONS

THIRD EDITION
FOOD SCIENCE AND TECHNOLOGY

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THIRD EDITION

edited by
CHING KUANG CHOW
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Preface

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

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

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

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

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

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

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

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

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I. INTRODUCTION

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

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

II. NOMENCLATURE

According to the strictest rules of nomenclature, a chemical name must identify and describe its chemical structure unambiguously. This is done by using systematic nomenclature, and there is no
possibility of mistaken identity when this system is used. The systematic method names fatty acids solely on the basis of the number of carbon atoms and the number and position of unsaturated bonds relative to the carboxyl group(s). Substituted groups and their positions are identified. Optical activity and geometric configuration at double bonds are also designated. Systematic nomenclature will be described generally for the saturated fatty acids and then for other types of fatty acids as necessary thereafter.

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

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

Also widely used is the structural system in which fatty acids are identified solely by carbon number and number of unsaturated double bonds. Morris (1961) has proposed that chain length be designated as C10, C20, and so forth, and the unsaturated double bonds be serialized. That is, either methylene-interrupted or conjugated, only the number of the carbon where the series begins will be indicated. For example, linolenic acid, or cis-9, cis-12, cis-15-octadecatrienoic acid, becomes C18:3Δ9c.

The Greek letters omega (ω) and delta (Δ) are sometimes used with special significance in naming fatty acids. Omega is often used to indicate how far a double bond is from the terminal methyl carbon irrespective of the chain length. Delta, followed by a numeral or numerals, is used to designate the presence and position of one or more double or triple bonds in the hydrocarbon chain counting from the carboxyl carbon. Thus, ordinary oleic acid is also named Δ9-octadecenoic acid.

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

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

Although the IUPAC system is unambiguous, some authors still select a nomenclature system according to their audience. Also, criteria for a suitable abbreviated terminology have been proposed but have yet to be universally adapted. Questions of which abbreviated terms are most appropriate
for representing the long and complicated chemical names will continue until an accepted system of nomenclature for individual fatty acids is agreed upon.

III. SATURATED FATTY ACIDS

The naturally occurring fatty acids can be grouped on the basis of the presence of double or triple bonds into two broad classes termed saturated and unsaturated. Most of the saturated fatty acids occurring in nature have unbranched structures with an even number of carbon atoms. They are referred to as normal alkanoic acids and may bear the prefix "n-," such as in n-hexanoic or n-octadecanoic. They have the general formula R–COOH, in which the R group is a straight-chain hydrocarbon of the form CH3(CH2)x or CnH2n+1. These acids range from short-chain-length volatile liquids to waxy solids having chain lengths of ten or more carbon atoms. Fatty acids from 2 to 30 carbons (or longer) do occur, but the most common and important acids contain between 12 and 22 carbons and are found in many different plant and animal fats. Under the systematic rules of nomenclature, the aliphatic acids are regarded as derivatives of hydrocarbons of the same number of carbon atoms (–CH3 is replaced by –COOH). The final "e" of the corresponding hydrocarbon (alkane) is replaced by the suffix "-oic"; for example, alkane becomes alkanoic. The unsaturated fatty acids are named in a similar manner, with alkene becoming alkenoic and alkyne becoming alkynoic. The presently accepted names for the hydrocarbons are given in Table 1.2. The tables in this and the following sections are representative only, not complete. Except for the first four members of the series (meth-, eth-, prop-, but-), which have trivial names, the prefix of the name cites the number of carbon atoms.

Saturated fatty acids are also functionally divided into short- and long-chain acids and are most widely known by their trivial names. Table 1.3 lists some of the most important saturated fatty acids. Also included is a system of abbreviated nomenclature that designates chain length and degree of unsaturation; for example, 18:0 designates an 18-carbon saturated fatty acid, whereas 18:2 indicates two double bonds. The location of unsaturations as well as conformation of double bonds can also be designated; 18:2Δ9c, 12c designates cis double bonds at the 9 and 12 carbons from the carboxyl group. Similar designations will be described for hydroxy, keto, and so on.

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

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

### TABLE 1.1

<table>
<thead>
<tr>
<th>Names</th>
<th>Abbreviation</th>
<th>Carboxyl-Reference</th>
<th>n- or ω-Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmitic acid</td>
<td>Hexadecanoic acid</td>
<td>16:0</td>
<td>16:0</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>Octadecanoic acid</td>
<td>18:0</td>
<td>18:0</td>
</tr>
<tr>
<td>Oleic acid</td>
<td>9-Octadecenoic acid</td>
<td>18:1Δ9</td>
<td>18:1n-9 or 18:1–9</td>
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<td>Linoleic acid</td>
<td>9,12-Octadecadienoic acid</td>
<td>18:2Δ9,12</td>
<td>18:2n-6 or 18:2–6</td>
</tr>
<tr>
<td>Linolenic acid</td>
<td>9,12,15-Octadecatrienoic acid</td>
<td>18:3Δ9,12,15</td>
<td>18:3n-3 or 18:3–3</td>
</tr>
<tr>
<td>Number of Carbons</td>
<td>Alkane $C_nH_{2n+2}$</td>
<td>Alkene $C_nH_{2n}$</td>
<td>Alkyne $C_nH_{2n-2}$</td>
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<tr>
<td>-------------------</td>
<td>-----------------------</td>
<td>-------------------</td>
<td>---------------------</td>
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<td>Ethane</td>
<td>Propene</td>
<td>Propyne&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Butene</td>
<td>Butyne</td>
</tr>
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<td>70</td>
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<td>Heptacontene</td>
<td>Heptacontyne</td>
</tr>
</tbody>
</table>

<sup>a</sup>Formerly ethine, propine, and so forth; <sup>b</sup>Also called allylene; <sup>c</sup>Also called amylene; <sup>d</sup>Formerly undecane; <sup>e</sup>Also called cetane.
about two dozens are the sources for most of the fatty acids. The fatty acid composition of a variety of fats and oils in foods can be found from the chapters of this volume and other sources (Brignoli et al., 1976; Pryde, 1979; Smith, 1979).

Although the majority of natural saturated fatty acids have a straight chain, there are many that have a branched chain. The branched-chain saturated fatty acids have systematic names consisting of two parts; the terminal portion is the name of the longest straight chain present in the compound, that is, the parent chain, and preceding this are the names of side chains. Arabic numbers indicate the locations of the branching. Such prefixes, called locants, are listed in numerical sequence from the carboxyl carbon and are separated from each other by commas and from the remainder of the name by a hyphen. The entire name is written as one word; for example, 2,3-dimethyloctadecanoic acid. Branched-chain fatty acids can be further divided into the iso acids, in which the methyl group is in the penultimate, referred to as ω-1, position from the carboxyl group, and the anteiso acids, in which the methyl group is in the ω-2 position. The anteiso isomers are optically active. (R) and (S) are absolute-configuration labels assigned to any asymmetrical carbon atoms and are preferred to the L and D labels. (R) is derived from the Latin word rectus, meaning right, and (S) from the Latin word sinister, meaning left. It is to describe the spatial relationship among the groups around the

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Formula</th>
<th>Abbreviation</th>
<th>Trivial Name</th>
</tr>
</thead>
<tbody>
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<td>CHOOH</td>
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</tr>
<tr>
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<td>Acetic</td>
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<tr>
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</tr>
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<tr>
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<td></td>
</tr>
<tr>
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<td>Palmitic</td>
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</tr>
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<td>Arachidic</td>
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<td>Behenic</td>
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<tr>
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<td>Dotricosanoic</td>
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<td>32:0</td>
<td>Lacceroic or lacceric</td>
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<tr>
<td>Tritricosanoic</td>
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<td>33:0</td>
<td>Psyllic or ceromelissic</td>
</tr>
<tr>
<td>Tetraricosanoic</td>
<td>CH₃(CH₂)₂₇–COOH</td>
<td>34:0</td>
<td>Geddic or gheddic</td>
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<tr>
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<td>CH₃(CH₂)₂₈–COOH</td>
<td>35:0</td>
<td>Ceroelastic</td>
</tr>
</tbody>
</table>
asymmetrical carbon (Cahn et al., 1956). The most common type of branch is a single methyl group, but sometimes there are longer branches or more than one branching methyl.

Iso and anteiso acids occur frequently but in small amounts in animal fats, waxes, and marine oils. For example, phytanic acid (3,7,11,15-tetramethylhexadecanoic acid) is an isoprenoid acid derived from the corresponding alcohol (phytol), and it is found in most land and marine fats. Also, phytenic acid is the corresponding C20 branched-chain acid with a double bond adjacent to the carboxyl group resulting from the corresponding alcohol phytol (Gunstone and Herslof, 1992). Although rare in plant lipids, branched-chain acids are major components of the lipids of gram-positive bacteria. More elaborate reviews of the branched-chain fatty acids are available (Shorland, 1956; Gensler, 1957; Hartman, 1957; Abrahamsson et al., 1964). Lipids of mycobacteria have also been found to contain a very complex mixture of branched-chain acids (Asselineau, 1966).

If a fatty acid contains two carboxyl groups, the suffix becomes -dioic; three carboxyls, -trioic; and so forth. The saturated dicarboxylic acids conform to the general formula \((\text{CH}_2)_n(\text{COOH})_2\). This series of acids is frequently referred to as the oxalic acid series. Like the members of most other acid series, the various dioic fatty acids are best known by their trivial (common) names. In the present accepted method of nomenclature, the carbon atom of the carboxyl group is considered part of the chain, and the acids are named according to the number of carbon atoms in the hydrocarbon chain, that is, alkanedioic. Table 1.4 lists the chemical names, formulas, and common names for some of the more important saturated dicarboxylic acids. The lower molecular weight dioic acids are easily recognizable as fatty acid and tricarboxylic acid cycle intermediates involved in many of the biochemical pathways in metabolism. Of somewhat less frequent occurrence are the higher molecular weight dioic acids.

### IV. UNSATURATED FATTY ACIDS

The unsaturated fatty acids may contain one or more double or triple bonds and so can be separated into monounsaturated, polyunsaturated, and acetylenic fatty acids. If an unsaturated fatty acid contains only double bonds, it is called an alkenoic, ethenoic, or olefinic acid. If it contains only triple bonds, it is called an alkynoic, ethynoic, or acetylenic acid. If the unsaturated fatty acid contains a number of double bonds in the hydrocarbon chain, the prefix di-, tri-, tetra-, and so forth, is inserted before “-enoic” to indicate the number of such double bonds (Table 1.1). An unsaturated fatty acid

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**TABLE 1.4**

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<tr>
<th>Chemical Name</th>
<th>Formula</th>
<th>Trivial Name</th>
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<tr>
<td>Ethanedioic</td>
<td>((\text{COOH})_2)</td>
<td>Oxalic</td>
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<td>((\text{CH}_2)(\text{COOH})_2)</td>
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<td>((\text{CH}_2)_4(\text{COOH})_2)</td>
<td>Adipic</td>
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<tr>
<td>Heptanedioic</td>
<td>((\text{CH}_2)_5(\text{COOH})_2)</td>
<td>Pimelic</td>
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<td>Octanedioic</td>
<td>((\text{CH}_2)_6(\text{COOH})_2)</td>
<td>Suberic</td>
</tr>
<tr>
<td>Nonanedioic</td>
<td>((\text{CH}_2)_7(\text{COOH})_2)</td>
<td>Azelaic</td>
</tr>
<tr>
<td>Decanedioic</td>
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<tr>
<td>Tridecanedioic</td>
<td>((\text{CH}_2)_9(\text{COOH})_2)</td>
<td>Brassyl</td>
</tr>
<tr>
<td>Hexadecanedioic</td>
<td>((\text{CH}<em>2)</em>{10}(\text{COOH})_2)</td>
<td>Thapsic</td>
</tr>
<tr>
<td>Heneicosanedioic</td>
<td>((\text{CH}<em>2)</em>{10}(\text{COOH})_2)</td>
<td>Japanic</td>
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</table>
with a double bond can have two possible configurations, either cis or trans, depending on the relative positions of the alkyl groups:

\[
\begin{array}{c}
\text{cis} \\
\text{trans}
\end{array}
\]

Most naturally occurring unsaturated fatty acids have the cis orientation. With systematic nomenclature, the prefix cis- or trans- precedes the unsaturation position. Some naturally occurring acids have trivial names that are sufficiently specific. For example, oleic and elaidic refer to the cis and trans forms, respectively, of 9-octadecenoic acid. In other trivial names containing “-oleic” and “-elaidic,” the former denotes a cis form and the latter a trans form. Thus, myristoleic refers to cis-9-tetradecenoic acid and by convention myristelaidic to trans-9-tetradecenoic acid.

More than 100 naturally occurring monounsaturated fatty acids have been identified, but most of these are very rare compounds. In general, these fatty acids have an even number of carbon atoms and the double bond has the cis conformation. Table 1.5 lists some of the more important monounsaturated fatty acids. Petroselinic acid (18:1\(\Delta_6c\)) is a positional isomer of oleic acid and occurs widely in seed oils of the order Umbellifere, usually along with oleic acid and other saturated and unsaturated fatty acids. Oleic acid is one of the most widely distributed fatty acids. It is a major component of safflower, pecan, pistachio, and macadamia nut oils and occurs in fish oils and animal fats (Holman, 1966). Some important oils containing erucic acid (22:1\(\Delta_13c\)) are rape, mustard, and Crambe abyssinica.

### TABLE 1.5
**Some Important Monounsaturated Acids**

<table>
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<tr>
<th>Systematic Name</th>
<th>Abbreviation</th>
<th>Trivial Name</th>
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<tr>
<td>9-Decenoic</td>
<td>10:1(\Delta_9) (9-10:1)</td>
<td>Caproleic</td>
</tr>
<tr>
<td>cis-4-Dodecenoic</td>
<td>12:1(\Delta_4c) (4c-12:1)</td>
<td>Linderic</td>
</tr>
<tr>
<td>cis-9-Dodecenoic</td>
<td>12:1(\Delta_9c) (9c-10:1)</td>
<td>Lauroleic</td>
</tr>
<tr>
<td>4-Tetradecenoic</td>
<td>14:1(\Delta_4) (4-14:1)</td>
<td>Obusilic</td>
</tr>
<tr>
<td>cis-4-Tetradecenoic</td>
<td>14:1(\Delta_4c) (4c-14:1)</td>
<td>Tsuzuic</td>
</tr>
<tr>
<td>cis-5-Tetradecenoic</td>
<td>14:1(\Delta_5c) (5c-14:1)</td>
<td>Physteric</td>
</tr>
<tr>
<td>cis-9-Tetradecenoic</td>
<td>14:1(\Delta_9c) (9c-14:1)</td>
<td>Myristoleic</td>
</tr>
<tr>
<td>cis-9-Hexadecenoic</td>
<td>16:1(\Delta_9c) (9c-16:1)</td>
<td>Palmitoleic</td>
</tr>
<tr>
<td>trans-9-Hexadecenoic</td>
<td>16:1(\Delta_9t) (9t-16:1)</td>
<td>Palmitelaidic</td>
</tr>
<tr>
<td>cis-6-Octadecenoic</td>
<td>18:1(\Delta_6c) (6c-18:1)</td>
<td>Petroselinic</td>
</tr>
<tr>
<td>cis-9-Octadecenoic</td>
<td>18:1(\Delta_9c) (9c-18:1)</td>
<td>Oleic</td>
</tr>
<tr>
<td>cis-11-Octadecenoic</td>
<td>18:1(\Delta_11c) (11c-18:1)</td>
<td>Asclepic or cis-vaccenic</td>
</tr>
<tr>
<td>trans-11-Octadecenoic</td>
<td>18:1(\Delta_11t) (11t-18:1)</td>
<td>Vaccenic</td>
</tr>
<tr>
<td>cis-9-Eicosenoic</td>
<td>20:1(\Delta_9c) (9c-20:1)</td>
<td>Gadoleic</td>
</tr>
<tr>
<td>trans-9-Eicosenoic</td>
<td>20:1(\Delta_9t) (9t-20:1)</td>
<td>Gadelaidic</td>
</tr>
<tr>
<td>cis-11-Docosenoic</td>
<td>22:1(\Delta_11c) (11c-22:1)</td>
<td>Cetoleic</td>
</tr>
<tr>
<td>cis-13-Docosenoic</td>
<td>22:1(\Delta_13c) (13c-22:1)</td>
<td>Erucic</td>
</tr>
<tr>
<td>trans-13-Docosenoic</td>
<td>22:1(\Delta_13t) (13t-22:1)</td>
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</tr>
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<tr>
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<td>26:1(\Delta_17c) (17c-26:1)</td>
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</tr>
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<td>cis-21-Triacosenoic</td>
<td>30:1(\Delta_21c) (21c-30:1)</td>
<td>Lumequic</td>
</tr>
</tbody>
</table>
Although most natural sources of unsaturated fats are of the cis configuration, trans fatty acids do occur in foods. Unsaturated fats are hydrogenated to produce solid fats for margarine and shortening product. Hydrogenation also improves the oxidative and flavor stability of the oils. However, this process can move double bonds from their naturally occurring positions and convert configurations from cis to trans, creating both positional and geometrical isomers. See Emken (1984) and Emken and Dutton (1979) for a review of geometrical and positional fatty acid isomers.

Polyunsaturated fatty acids, sometimes referred to as PUFAs or polyalkenoic acids, can be divided into a number of categories depending on the relative positions of the double bonds. When double-bonded carbon atoms alternate with single bonds, that is, (–C=–C=–), the acid is referred to as conjugated. If the double bonds are separated by one or more carbon atoms with only single bonds (–C=C–C, –C=C–), the acid is said to be unconjugated. Unconjugated fatty acids usually occur in a methylene-interrupted arrangement. A third group, frequently described as nonmethylene-interrupted dienes, has double bonds that are not entirely in a methylene-interrupted arrangement. If a single carbon atom has two double bonds, that is, (–C=–C=–), then it is called allenic. These acids are chiral by virtue of their allenic group. Examples are laballenic acid [H3C(CH2)10CH=C=CH(CH2)3COOH] and lamenallenic acid [H3CCH=CH(CH2)8CH=C=CH(CH2)3COOH] (Gunstone and Herslof, 1992).

The most common conjugated polyunsaturated acids are trienes such as octadecatrienoic acids, of which seven isomers occur naturally. Conjugated dienes do exist—for example, 2,4-hexadienoic or sorbic acid and trans-2-cis-4-decadeinoic, which is a known flavor component in the Bartlett pear (Jennings et al., 1964)—but do not occur extensively. Seven conjugated octadecatrienoic acids have been identified as natural compounds, including three 8,10,12-trienes and four 9,11,13-trienes. Systematic and trivial names and some indication of occurrence are given in Table 1.6. These acids are all believed to arise from linoleic acid (18:2\(\Delta_9,12\)) by oxidation and dehydration mechanisms. Reviews have been published by Smith (1971, 1979), Pohl and Wagner (1972), Hopkins (1972), Pryde (1979), and Badami and Patil (1980). Conjugated PUFAs are in limited abundance in animal fats and occur extensively in only a few seed oils.

The unconjugated and methylene-interrupted PUFAs are probably the most important PUFAs in terms of extent of occurrence. These acids have been arranged into families based on the number of carbons on which the methylene-interrupted double bonds begin. The acids are categorized into n-1 through n-12 families. These symbols indicate the carbon number counting from the methyl end. Formerly, the terms \(\omega_1\) to \(\omega_{12}\) were used. The most important families are the n-3, n-6, and n-9 acids. Monounsaturated acids can be included in this family system, with oleic being an important

### Table 1.6

<table>
<thead>
<tr>
<th>Systematic Name</th>
<th>Trivial Name</th>
<th>Typical Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trienes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8c,10t,12c-Octadecatrienoic</td>
<td>Jacaric</td>
<td><em>Jacaranda minosifolia</em></td>
</tr>
<tr>
<td>8t,10t,12c-Octadecatrienoic</td>
<td>Calendic</td>
<td><em>Calendula officinalis</em></td>
</tr>
<tr>
<td>8t,10t,12t-Octadecatrienoic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9c,11t,13c-Octadecatrienoic</td>
<td>Catalpic</td>
<td><em>Catalpa ovata</em></td>
</tr>
<tr>
<td>9c,11t,13t-Octadecatrienoic</td>
<td>(\alpha)-Eleostearic</td>
<td>Tung oil</td>
</tr>
<tr>
<td>9t,11t,13c-Octadecatrienoic</td>
<td>Punthic</td>
<td><em>Punica granatum</em></td>
</tr>
<tr>
<td>9t,11t,13t-Octadecatrienoic</td>
<td>(\beta)-Eleostearic</td>
<td></td>
</tr>
<tr>
<td><strong>Tetraenes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9c,11t,13t,15c-Octadecatetraenoic</td>
<td>(\alpha)-Parinaric</td>
<td><em>Impatiens balsamina</em></td>
</tr>
<tr>
<td>9t,11t,13t,15t-Octadecatetraenoic</td>
<td>(\beta)-Parinaric</td>
<td></td>
</tr>
</tbody>
</table>
member of the n-9 family. Table 1.7 lists some of the more important natural fatty acids arranged by families. The acids within each family are biosynthetically related, being interconverted by enzymatic processes of desaturation, chain elongation, and chain shortening. One of the most familiar and widespread fatty acids is linoleic, which is also nutritionally essential. Natural linoleic acid is predominately the cis–cis isomer. It occurs in almost every vegetable fat, with rich amounts in corn, cottonseed, safflower, sunflower, and soybean oils. It is present in animal fats and fish oils at much lower levels. An important n-3 fatty acid is α-linolenic. This fatty acid is a major component of linseed oil and is valuable in paints because of its drying properties. Linolenic acid is the major fatty acid of plant leaves, stems, and roots, and is also a significant component of many photosynthetic organisms (Hilditch and Williams, 1964). The other two important n-3 acids are eicosapentaenoic acid and docosahexaenoic acid, which are primarily found in fish oils and marine algae. The C20 acid is also a precursor of some prostaglandins and thromboxanes. Arachidonic acid, an n-6 acid, is best known as a precursor to the prostaglandins, thromboxanes, and leukotrienes. It is present in animal fats and at lower levels in many fish oils.

There are also a number of PUFAs in which the unsaturation is not completely methylene interrupted. These acids are thought to occur by insertion of an additional double bond into the more common poly- and monounsaturated compounds. These fatty acids are seen in some seed oils, certain microorganisms, and marine lipids. Table 1.8 lists natural nonmethylene-interrupted PUFAs.

The acetylenic acids are composed of a series of straight-chain carboxylic acids characterized by the presence of one or more triple carbon–carbon bonds (–C≡C–) in the hydrocarbon chain. They are therefore conveniently divided into those with only one triple bond and those with more than one. In the former group of acids, one or more double bonds can occur, and unsaturation frequently appears in the conventional methylene-interrupted pattern. Alkenoic acids containing a triple bond must be named with the positions of the double and triple bonds in mind; for example, 11-octadecene-9-ynoic is an 18-carbon fatty acid with the double bond at position 11 and the triple bond at position 9. In general, most natural acetylenic acids are C18 compounds with conjugated unsaturation involving one or more acetylenic groups along with olefinic unsaturation (usually at C-9), which may be cis or trans. Table 1.9 lists some of the more common acetylenic acids. Acetylenic acids are rarely found in naturally occurring fats and oils; they are seen only in a number of rare seed oils and in some mosses. The first acetylenic compound identified in nature was the 18-carbon tariric acid found by

### TABLE 1.7

<table>
<thead>
<tr>
<th>Family</th>
<th>Systematic Name</th>
<th>Abbreviation</th>
<th>Trivial Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>n-3</td>
<td>9,12,15-Octadecatrienoic</td>
<td>18:3(n-3)</td>
<td>α-Linolenic</td>
</tr>
<tr>
<td></td>
<td>6,9,12,15-Octadecatetraenoic</td>
<td>18:4(n-3)</td>
<td>Stearidonic or moroctic</td>
</tr>
<tr>
<td></td>
<td>5,8,11,14,17-Eicosapentaenoic</td>
<td>20:5(n-3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4,7,10,13,16,19-Docosahexaenoic</td>
<td>22:6(n-3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6,9,12,15,18,21-Tetracosaheaxanenoic</td>
<td>24:6(n-3)</td>
<td>Nisinic</td>
</tr>
<tr>
<td>n-6</td>
<td>9,12-Octadecadienoic</td>
<td>18:2(n-6)</td>
<td>Linoleic</td>
</tr>
<tr>
<td></td>
<td>6,9,12-Octadecatrienoic</td>
<td>18:3(n-6)</td>
<td>γ-Linolenic</td>
</tr>
<tr>
<td></td>
<td>8,11,14-Eicosatrienoic</td>
<td>20:3(n-6)</td>
<td>Dihomo-γ-linolenic</td>
</tr>
<tr>
<td></td>
<td>5,8,11,14-Eicosatetraenoic</td>
<td>20:4(n-6)</td>
<td>Arachidonic</td>
</tr>
<tr>
<td></td>
<td>7,10,13,16-Docosatetraenoic</td>
<td>22:4(n-6)</td>
<td>Adrenic</td>
</tr>
<tr>
<td>n-7</td>
<td>9-Hexadecenoic</td>
<td>16:1(n-7)</td>
<td>Palmitoleic</td>
</tr>
<tr>
<td></td>
<td>11-Octadecenoic</td>
<td>18:1(n-7)</td>
<td>Vaccenic</td>
</tr>
<tr>
<td>n-9</td>
<td>9-Octadecenoic</td>
<td>18:1(n-9)</td>
<td>Oleic</td>
</tr>
<tr>
<td></td>
<td>15-Tetracosenoic</td>
<td>24:1(n-9)</td>
<td>Nervonic or selacholeic</td>
</tr>
<tr>
<td></td>
<td>5,8,11-Eicosatrienic</td>
<td>20:3(n-9)</td>
<td>Mead’s</td>
</tr>
</tbody>
</table>
TABLE 1.8
Natural Nonmethylene-Interrupted Polyunsaturated Acids

<table>
<thead>
<tr>
<th>Systematic Name</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,9-Octadecadienoic</td>
<td>18:2Δ5,9</td>
</tr>
<tr>
<td>5,11-Octadecadienoic</td>
<td>18:2Δ5,11</td>
</tr>
<tr>
<td>2t,9,12-Octadecatrienoic</td>
<td>18:3Δ2t,9,12</td>
</tr>
<tr>
<td>3t,9,12-Octadecatrienoic</td>
<td>18:3Δ3t,9,12</td>
</tr>
<tr>
<td>5t,9,12-Octadecatrienoic</td>
<td>18:3Δ5t,9,12</td>
</tr>
<tr>
<td>5,9,12-Octadecatrienoic</td>
<td>18:3Δ5,9,12</td>
</tr>
<tr>
<td>5,11,14-Octadecatrienoic</td>
<td>18:3Δ5,11,14</td>
</tr>
<tr>
<td>3t,9,12,15-Octadecatetraenoic</td>
<td>18:3Δ3t,9,12,15</td>
</tr>
<tr>
<td>5,9,12,15-Octadecatetraenoic</td>
<td>18:3Δ5,9,12,15</td>
</tr>
<tr>
<td>5,11-Eicodadienoic</td>
<td>20:2Δ5,11</td>
</tr>
<tr>
<td>5,13-Eicodadienoic</td>
<td>20:2Δ5,13</td>
</tr>
<tr>
<td>7,11-Eicosadienoic</td>
<td>20:2Δ7,11</td>
</tr>
<tr>
<td>7,13-Eicosadienoic</td>
<td>20:2Δ7,13</td>
</tr>
<tr>
<td>5,11,14-Eicosatrienoic</td>
<td>20:3Δ5,11,14</td>
</tr>
<tr>
<td>7,11,14-Eicosatrienoic</td>
<td>20:3Δ7,11,14</td>
</tr>
<tr>
<td>5,11,14,17-Eicosatetraenoic</td>
<td>20:4Δ5,11,14,17</td>
</tr>
<tr>
<td>5,11-Docosadienoic</td>
<td>22:2Δ5,11</td>
</tr>
<tr>
<td>5,13-Docosadienoic</td>
<td>22:2Δ5,13</td>
</tr>
<tr>
<td>7,13-Docosadienoic</td>
<td>22:2Δ7,13</td>
</tr>
<tr>
<td>7,15-Docosadienoic</td>
<td>22:2Δ7,15</td>
</tr>
<tr>
<td>7,17-Docosadienoic</td>
<td>22:2Δ7,17</td>
</tr>
<tr>
<td>9,13-Docosadienoic</td>
<td>22:2Δ9,13</td>
</tr>
<tr>
<td>9,15-Docopadienoic</td>
<td>22:2Δ9,15</td>
</tr>
</tbody>
</table>

TABLE 1.9
Acetylenic Acids

<table>
<thead>
<tr>
<th>Systematic Name</th>
<th>Abbreviation</th>
<th>Trivial Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>10t-Heptadecene-8-ynoic</td>
<td>17:2Δ8a,10t</td>
<td>Pyrulilc</td>
</tr>
<tr>
<td>6-Octadecynoic</td>
<td>18:1Δ6a</td>
<td>Tariric</td>
</tr>
<tr>
<td>9-Octadecynoic</td>
<td>18:1Δ9a</td>
<td>Stearolic</td>
</tr>
<tr>
<td>11t-Octadecene-9-ynoic</td>
<td>18:2Δ9a,11t</td>
<td>Ximenylic or santalbic</td>
</tr>
<tr>
<td>8-Hydroxy-11t-octadecene-9-ynoic</td>
<td>18:2Δ9a,11t-8OH</td>
<td>Ximenylic</td>
</tr>
<tr>
<td>17c-Octadecene-9,11-diynoic</td>
<td>18:3Δ9a,11a,17c</td>
<td>Isanic or erythrogenic</td>
</tr>
<tr>
<td>8-Hydroxy-17c-Octadecene-9,11-diynoic</td>
<td>18:3Δ9a,11a,17c-8OH</td>
<td>Isanolic</td>
</tr>
<tr>
<td>9c-Octadecene-12-ynoic</td>
<td>18:2Δ9c,12a</td>
<td>Crepenylic</td>
</tr>
<tr>
<td>13t-Octadecene-9,11-diynoic</td>
<td>18:3Δ13t,9a,11a</td>
<td>Exocarpic</td>
</tr>
</tbody>
</table>

The presence of “a” in the abbreviation denotes the triple bond.

Arnaud in a fatty oil in 1892. Compounds up to the pentyne stage have been isolated, but from triyne onwards some of the fatty acids become increasingly unstable and even explosive. Bohlmann et al. (1973) described crepenylic (18:2Δ9c12a), isolated from the seed oil of Crepis foetida, as one of the most important monoacetylenic acids. See Meade (1957) for a review on the naturally occurring acetylenic acids.
V. OXYGENATED FATTY ACIDS

The naturally occurring oxygenated fatty acids include the hydroxyl, keto, and epoxy groups, of which the hydroxy-substituted acids are most common. As mentioned previously, if one or more hydrogen atoms of the hydrocarbon chain are replaced with some other atom or group, such as a hydroxyl or keto, the acid may retain its specific name and be prefixed by the name and position of the substituent atom or group, such as 2-hydroxybutanoic acid and 9,10-dihydroxyoctadecanoic acid.

The hydroxy fatty acids are composed of a series of straight-chain carboxylic acids that contain one or more hydroxyl groups substituted on the hydrocarbon portion of the molecule. Since the hydroxy fatty acids possess at least one asymmetrical carbon atom, they are capable of being resolved into their optical isomers. Most of the naturally occurring hydroxy acids are optically active. The hydroxy fatty acids may be saturated, or they may contain one or more unsaturated bonds in the hydrocarbon chain. Those hydroxy acids that contain an ethylenic bond exhibit geometrical isomerism and can be obtained in either the cis or trans form. Natural monohydroxy acids that are either saturated or contain unconjugated unsaturation are listed in Table 1.10. The hydroxy position precedes the name of the substituted hydrocarbon chain and is followed with any stereochemical designations. Ricinoleic acid (12-hydroxyoleic) is the best known, being the major acid in castor oil. In all of these 18- and 20-carbon acids, the hydroxy groups are in the 3 and/or 4 positions from the methyl end. Hydroxy acids with conjugated unsaturation (cis and/or trans olefinic and/or acetylenic) are listed in Table 1.11.

### TABLE 1.10
Hydroxy Acids without Conjugated Unsaturation

<table>
<thead>
<tr>
<th>Systematic Name</th>
<th>Abbreviation</th>
<th>Trivial Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-Hydroxydecanoic</td>
<td>12:0-12OH</td>
<td>Sabinic</td>
</tr>
<tr>
<td>6-Hydroxytetradecanoic</td>
<td>14:0-6OH</td>
<td>Butolic</td>
</tr>
<tr>
<td>11-Hydroxytetradecanoic</td>
<td>14:0-11OH</td>
<td>Convolvulinic</td>
</tr>
<tr>
<td>11-Hydroxyhexadecanoic</td>
<td>16:0-11OH</td>
<td>Jalapinolic</td>
</tr>
<tr>
<td>16-Hydroxyhexadecanoic</td>
<td>16:0-16OH</td>
<td>Juniperic</td>
</tr>
<tr>
<td>16-Hydroxy-7c-hexadecanoic</td>
<td>16:1Δc-16OH</td>
<td>Ambrettolic</td>
</tr>
<tr>
<td>12(R)-Hydroxy-9c-octadecanoic</td>
<td>18:1Δc-12OH</td>
<td>Ricinoleic</td>
</tr>
<tr>
<td>9(S)-Hydroxy-12c-octadecanoic</td>
<td>18:1Δ12c-9OH</td>
<td>Isorcinoleic</td>
</tr>
<tr>
<td>12(R)-Hydroxy-9c,15c-octadecanoic</td>
<td>18:2Δc,15c-12OH</td>
<td>Densipolic</td>
</tr>
<tr>
<td>14(R)-Hydroxy-11c-eicosanoic</td>
<td>20:1Δ11c-14OH</td>
<td>Lesquerolic</td>
</tr>
<tr>
<td>14-Hydroxy-11c,17c-eicosadienoic</td>
<td>20:2Δ11c,17c-14OH</td>
<td>Auricolic</td>
</tr>
<tr>
<td>22-Hydroxydocosanoic</td>
<td>22:0-22OH</td>
<td>Phellonic</td>
</tr>
</tbody>
</table>

### TABLE 1.11
Hydroxy Acid with Conjugated Unsaturation

<table>
<thead>
<tr>
<th>Systematic Name</th>
<th>Abbreviation</th>
<th>Trivial Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-Hydroxy-11t-octadecene-9-ynoic</td>
<td>18:2Δ9a,11t-8OH</td>
<td>Ximenynolic</td>
</tr>
<tr>
<td>8-Hydroxy-17c-octadecene-9,11-diynoic</td>
<td>18:3Δ9a,11a,17c-8OH</td>
<td>Isanolic</td>
</tr>
<tr>
<td>9-Hydroxy-10t,12t-octadecadienoic</td>
<td>18:2Δ10t,12t-9OH</td>
<td>Dimorphhecolic</td>
</tr>
<tr>
<td>9-Hydroxy-10t,12c-octadecadienoic</td>
<td>18:2Δ10t,12c-9OH</td>
<td>Helynolic</td>
</tr>
<tr>
<td>13-Hydroxy-9c,11t-octa decadienoic</td>
<td>18:2Δ9c,11t-13OH</td>
<td>Coriolic or artemesic</td>
</tr>
<tr>
<td>18-Hydroxy-9c,11t,13t-octadecatrienoic</td>
<td>18:3Δ9c,11t,13t-18OH</td>
<td>Kamlolenic</td>
</tr>
</tbody>
</table>
The polyhydroxy fatty acids are also a distinctive group that range in chain length from C₁₄ to C₉₆. The acids with 2–5 hydroxy groups are usually saturated, and the C₁₆ and C₁₈ acids are the most common. Several long-chain polyhydroxy acids that contain adjacent hydroxy groups produce asymmetrical centers and have been isolated from natural sources (Hilditch and Williams, 1964). The prefixes cis- and trans- used by many investigations in naming these open-chain compounds should be replaced by threo- and erythro-. By definition, threo compounds result by trans addition to a cis-ethylenic compound or by cis addition to a trans-ethylenic compound, and the erythro isomers are the products of cis addition to a cis-ethylenic or trans addition to a trans-ethylenic compound.

Table 1.12 lists some of the most common polyhydroxy fatty acids.

Natural hydroxy acids do not occur extensively, although they are very important industrial sources of synthetic oils. They occur in sphingolipids, stillingia oil, leaf waxes, and fungal and bacterial lipids. Unsaturated oils often contain small amounts of hydroxy and epoxy acids after prolonged storage, probably as a result of oxidation. See Downing (1961) for a review of the naturally occurring aliphatic hydroxy acids found in animals, plants, and microorganisms.

Mycolic acids are a series of very complex hydroxy fatty acids with high molecular weights. These acids occur in a wide range of microorganisms. They are generally 2-alkyl-3-hydroxy acids with the structure shown below.

\[ R{-}\text{CH(OH)}{-}\text{CH}{\text{[CH}_2]_n{-}\text{CH}_3} \]

These fatty acids may contain up to 80 carbons and may even contain one or more cyclopropane units (Polgar, 1971).

The epoxy fatty acids are characterized by the presence of a cyclic bond between two carbons in the chain and one oxygen atom. The epoxy carbons are counted in the longest hydrocarbon chain, and the acids are named accordingly. The name of the acid is prefixed by the two positions of the epoxy carbons attached to the prefix “epoxy.” Epoxy carbons also allow cis or trans conformations to occur, and this is also designated; for example, cis-9,10-epoxyoctadecanoic acid describes an 18-carbon acid with an epoxy group at positions 9 and 10 of the cis configuration.

\[ \text{CH}_3(\text{CH}_2)_7{-}\text{CH}{\text{[CH}_2]_7{-}\text{COOH}} \]

The epoxy fatty acids are another group of acids known to develop in some seed oils after prolonged storage (Gunstone et al., 1986). Natural epoxy acids occur in seed oils as triacylglycerols and in cutins as polymers of hydroxy acids. The best known and most widely occurring of the natural epoxy acids is vernolic acid (cis-12,13-epoxy-cis-9-octadecenoic), which was first investigated as the characteristic epoxy acid of Vernonia anthelmintica. Coronaric acid (cis-9,10-epoxy-cis-12-octadecenoic), a positional isomer of vernolic acids, is the second most common epoxy acid, and sometimes the two acids occur together.

**TABLE 1.12**

<table>
<thead>
<tr>
<th>Systematic Name</th>
<th>Abbreviation</th>
<th>Trivial Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,11-Dihydroxytetradecanoic</td>
<td>14:0-3,11-diOH</td>
<td>Ipurolic</td>
</tr>
<tr>
<td>threo-12,13-Dihydroxyhexadecanoic</td>
<td>16:0-12,13-diOH</td>
<td>Dihydroxystearic</td>
</tr>
<tr>
<td>2,15,16-Trihydroxyhexadecanoic</td>
<td>16:0-2,15,16-triOH</td>
<td>Ustilic</td>
</tr>
<tr>
<td>9,10,16-Trihydroxyhexadecanoic</td>
<td>16:0-9,10,16-triOH</td>
<td>Aleuritic</td>
</tr>
<tr>
<td>threo-9,10-Dihydroxyoctadecanoic</td>
<td>18:0-9,10-diOH</td>
<td></td>
</tr>
<tr>
<td>threo-12,13-Dihydroxy-9c-octadecenoic</td>
<td>18:1Δ9c-12,13-diOH</td>
<td>Dihydroxyoleic</td>
</tr>
</tbody>
</table>

The polyhydroxy fatty acids are also a distinctive group that range in chain length from C₁₄ to C₉₆. The acids with 2–5 hydroxy groups are usually saturated, and the C₁₆ and C₁₈ acids are the most common. Several long-chain polyhydroxy acids that contain adjacent hydroxy groups produce asymmetrical centers and have been isolated from natural sources (Hilditch and Williams, 1964). The prefixes cis- and trans- used by many investigations in naming these open-chain compounds should be replaced by threo- and erythro-. By definition, threo compounds result by trans addition to a cis-ethylenic compound or by cis addition to a trans-ethylenic compound, and the erythro isomers are the products of cis addition to a cis-ethylenic or trans addition to a trans-ethylenic compound. Table 1.12 lists some of the most common polyhydroxy fatty acids.

Natural hydroxy acids do not occur extensively, although they are very important industrial sources of synthetic oils. They occur in sphingolipids, stillingia oil, leaf waxes, and fungal and bacterial lipids. Unsaturated oils often contain small amounts of hydroxy and epoxy acids after prolonged storage, probably as a result of oxidation. See Downing (1961) for a review of the naturally occurring aliphatic hydroxy acids found in animals, plants, and microorganisms.

Mycolic acids are a series of very complex hydroxy fatty acids with high molecular weights. These acids occur in a wide range of microorganisms. They are generally 2-alkyl-3-hydroxy acids with the structure shown below.

\[ R{-}\text{CH(OH)}{-}\text{CH}{\text{[CH}_2]_n{-}\text{CH}_3} \]

These fatty acids may contain up to 80 carbons and may even contain one or more cyclopropane units (Polgar, 1971).

The epoxy fatty acids are characterized by the presence of a cyclic bond between two carbons in the chain and one oxygen atom. The epoxy carbons are counted in the longest hydrocarbon chain, and the acids are named accordingly. The name of the acid is prefixed by the two positions of the epoxy carbons attached to the prefix “epoxy.” Epoxy carbons also allow cis or trans conformations to occur, and this is also designated; for example, cis-9,10-epoxyoctadecanoic acid describes an 18-carbon acid with an epoxy group at positions 9 and 10 of the cis configuration.

\[ \text{CH}_3(\text{CH}_2)_7{-}\text{CH}{\text{[CH}_2]_7{-}\text{COOH}} \]

The epoxy fatty acids are another group of acids known to develop in some seed oils after prolonged storage (Gunstone et al., 1986). Natural epoxy acids occur in seed oils as triacylglycerols and in cutins as polymers of hydroxy acids. The best known and most widely occurring of the natural epoxy acids is vernolic acid (cis-12,13-epoxy-cis-9-octadecenoic), which was first investigated as the characteristic epoxy acid of Vernonia anthelmintica. Coronaric acid (cis-9,10-epoxy-cis-12-octadecenoic), a positional isomer of vernolic acids, is the second most common epoxy acid, and sometimes the two acids occur together.
The keto fatty acids comprise a group of straight-chain carboxylic acids that contain one or more carbonyl groups in the hydrocarbon portion of the molecule. The hydrocarbon chain may be either saturated or unsaturated. The naming of keto acids is similar to that of the hydroxy acids, with the keto position prefixing the fatty acid; for example, licanic acid or 4-keto-9,11,13-octadecatrienoic (18:3\(\Delta^4\)-oxo-9c, 11t, 13t) and lactarinic acid (6-oxo-octadecanoic acid). The properties of specific keto acids depend on the position of the keto group relative to the carboxyl group. Keto acids are rarely found in naturally occurring fats and oils.

---

**TABLE 1.13**

**Cyclic Fatty Acids**

1. The cyclopropanes

\[
\text{CH}_3-(\text{CH}_2)_5-C-C-(\text{CH}_2)_6\text{COOH}
\]

10-(2-Hexyl-cyclopropyl)decanoic, 11,12-methylenoctadecanoic (lactobacillic or phytonomic)

2. The cyclopropanes

\[
\text{CH}_3-(\text{CH}_2)_5-C=C-(\text{CH}_2)_6\text{COOH}
\]

<table>
<thead>
<tr>
<th>x</th>
<th>Cyclopropene Trivial Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>8-(2-Octyl-cyclopropyl)octanoic Sterculic</td>
</tr>
<tr>
<td>6</td>
<td>7-(2-Octyl-cyclopropyl)heptanoic Malvalic</td>
</tr>
</tbody>
</table>

3. The cyclopentenes

a. Monoene acid

\[
\text{HC}=\text{CH} \quad \text{CH}-(\text{CH}_2)_x\text{COOH} \quad \text{C}_2\text{H} \quad \text{CH}_2
\]

<table>
<thead>
<tr>
<th>x</th>
<th>Cyclopentene Trivial Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3-(2-Cyclopentenyl)methanoic Aleprolic</td>
</tr>
<tr>
<td>2</td>
<td>3-(2-Cyclopentenyl)proanoic Alepramic</td>
</tr>
<tr>
<td>4</td>
<td>5-(2-Cyclopentenyl)pentanoic Aleprastic</td>
</tr>
<tr>
<td>6</td>
<td>7-(2-Cyclopentenyl)heptanoic Aleprylic</td>
</tr>
<tr>
<td>8</td>
<td>9-(2-Cyclopentenyl)nonanoic Alepric</td>
</tr>
<tr>
<td>10</td>
<td>11-(2-Cyclopentenyl)undecanoic Hydnocarpic</td>
</tr>
<tr>
<td>12</td>
<td>13-(2-Cyclopentenyl)dodecanoic Chaulmoogric</td>
</tr>
<tr>
<td>14</td>
<td>15-(2-Cyclopentenyl)pentaeanoic Hormelic</td>
</tr>
</tbody>
</table>

b. Diene acids

\[
\text{HC}=\text{CH} \quad \text{CH}-(\text{CH}_2)_x\text{CH}==\text{CH}-(\text{CH}_2)_y\text{COOH} \quad \text{C}_2\text{H} \quad \text{CH}_2
\]

<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
<th>Cyclopentene Trivial Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4</td>
<td>11-(2-Cyclopentenyl)-4-undecenoic Manaonic</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>13-(2-Cyclopentenyl)-6-tridecenoic Gorlic</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>15-(2-Cyclopentenyl)-6-pentadecenoic Oncobic</td>
</tr>
</tbody>
</table>
VI. CYCLIC FATTY ACIDS
The cyclic fatty acids may contain a cyclic unit with three (cyclopropane and cyclopropene acids), five (prostaglandins and cyclopentene acids), or even six carbon atoms (cyclohexane acids). Most of these acids are known by their trivial names. The systematic name is derived again from the hydrocarbon chain including the carboxyl but not the cyclic structure. The cyclic structure and any R groups prefix the fatty acid name, with their position designated; for example, 8(-2octyl-cyclopropenyl) octanoic describes an eight-carbon fatty acid attached with a terminal cyclopropene that contains an eight-carbon alkyl group. Table 1.13 lists some of the more common cyclic fatty acids with their structures.

The cyclopropane fatty acids occur frequently in bacterial membrane phospholipids. They also generally accompany the cyclopropene acids in seed oils. Although other chain lengths have been reported, the most common cyclopropane acids are the cis 17-carbon and cis 19-carbon (lactobacillic acid) compounds. The cyclopropene acids have been identified in seed oil triacylglycerols. They are found mainly among Malvales, especially Sterculiaceae, Malvalaceae, Bombaceae, and Tiliaceae. In addition to the seeds, the cyclic acids are found in leaves, stems, and roots and are present mainly as glycerides. See Badami and Patil (1980), Christie (1970), and Lie Ken Jie (1979) for information with respect to these fatty acids.

VII. CONCLUSION
This chapter describes a number of naming systems, some of which are more popular than others. The IUPAC system for naming chemical compounds is the most comprehensive for naming fatty acids. This system permits the unambiguous naming of all the fatty acids. The abbreviated nomenclature, with carboxyl-reference or n-/ω-reference, found in the tables is aimed to provide a coherent way to substitute the trivial names or chemical names. The abbreviated terminology for naming fatty acids, when standardized, will be of great value in presentation and written formats for both laymen and professionals.

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Cooked 0.027 0.003 0.005 0.050 0.009 0.060 0.029 0.005

Raw 0.034 0.004 0.006 0.064 0.012 0.076 0.037 0.006


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LESSER KNOWN FRUIT AND FRUIT PRODUCTS RICH IN 18:1 FATTY ACID

LESSER KNOWN FRUIT AND FRUIT PRODUCTS RICH IN 18:2 FATTY ACID


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Chapter 14. Fatty Acid Content of Convenience Foods


I. INTRODUCTION

Hydrogenated fat has been an important component of the Western diet. The use of margarine and other products made from hydrogenated fat increased as consumers became concerned about their intake of saturated fat and cholesterol. Vegetable oils used in the manufacture of margarine contain
polyunsaturated fatty acids that are modified in structure during processing. Similarly, dairy products and meats from ruminant animals contain fat that has been modified by biohydrogenation. The term isomeric in reference to dietary fat generally refers to those fatty acids that are formed as a result of partial hydrogenation of unsaturated fat. Whether the process occurs in a commercial plant or in the rumen of an animal, double bonds originally present are modified in both conformation and position.

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I. Introduction

II. Forms and Sources of Dietary Isomeric Fatty Acids

 III. Positional Isomers of Fatty Acids in Food

 IV. Trans-Isomers of Fatty Acids in Foods

 V. Estimates of Isomeric Fatty Acids in the Diet

 VI. Concluding Perspective

Acknowledgments

The question of whether or not isomeric fatty acids should be termed unnatural has been debated (Applewhite, 1981; Sommerfeld, 1983; Wood, 1983). Isomeric fatty acids are formed by biohydrogenation in the rumen of animals and thus appear "naturally" in meat and dairy products. On the other hand, the commercial process of partial hydrogenation by which margarines and shortenings are manufactured results in the presence of isomeric fatty acids considered to be "unnatural," because they were not present in the original vegetable oils. The issue, however, is not one of se
tics but one of whether current amounts of these isomeric fatty acids in the food supply are having an effect on the health of populations consuming hydrogenated fat. Concerns have been raised about the possible effects of these isomeric fatty acids in promoting the incidence of cardiovascular disease (Kummerow, 1975, 1979; Vergroesen and Gottenbos, 1975; Kritchevsky, 1983; Mensink and Katan, 1990; Siguel and Lerman, 1993; Willett et al., 1993; Judd et al., 1994; Aró, 1998; Mensink and Zock, 1998; Stender and Dyerberg, 2004; Mozaffarian et al., 2006) and cancer (Enig et al., 1978). Additionally, there has been concern about possible detrimental effects of trans-fatty acids in infant development (Koletzko, 1992, 1994; Berra, 1993; van Houwelingen and Hornstra, 1994; International Life Sciences Institute Expert Panel on Trans-Fatty Acids and Early Development, 1997; Craig-Schmidt, 2001). On the other hand, conjugated linoleic acid (CLA; predominantly 9-cis, 11-trans-octadecadienoic acid) found principally in ruminant products in small, but significant, quantities is believed to be antiatherogenic and anticarcinogenic. This active area of research has been reviewed by Pariza et al. (1991), Parodi (1994), Ip et al. (1994), Chardigny et al. (1996a), Ip (1997), and Banni and Martin (1998). The physiological effects of isomeric fatty acids as they are metabolized and incorporated into membranes have been reviewed by a number of authors (Aaes-Jørgensen, 1966; Kummerow, 1974, 1975, 1979, 1986; Kaunitz, 1976; Aln-Slater and Aftergood, 1979; Emken, 1979, 1981, 1983, 1984; Applewhite, ...
1981; Brisson, 1981; Kinsella, 1981; Kinsella et al., 1981; Beare-Rogers, 1983a; Gottenbos, 1983; Holman et al., 1983; Holmer, 1998; Sebedio and Chardigny, 1998) and are beyond the scope of this chapter. The studies on the physiological effects of isomeric fatty acids, however, cannot be properly interpreted unless they are put in the context of consumption data. The purpose of this chapter is thus to summarize what is known to date about the amounts and types of isomeric fatty acids in various foods and to review current estimates of isomeric fatty acids in the food supply. Earlier reviews of this topic include the Canadian Report of the Ad Hoc Committee on the Composition of Special Margarines (Spence et al., 1980), an article by Sommerfeld (1983) that emphasizes work done in Germany and other European countries, and a report by the Life Sciences Research Office for the U.S. Food and Drug Administration (Senti, 1985). Hunter and Applewhite (1986), Enig et al. (1990a), Craig-Schmidt (1998), and Craig-Schmidt (2006) review estimates of isomeric fatty acids in the diet but do not summarize the food composition data of individual food items. Additional reviews include (1) a report by the International Life Science Institute Expert Panel on Trans-Fatty Acids and Coronary Heart Disease (1995); (2) the American Society for Clinical Nutrition/American Institute of Nutrition Task Force on Trans-Fatty Acids (1996); (3) the International Life Sciences Institute Expert Panel on Trans-Fatty Acids and Early Development (1997); (4) two reports by the British Nutrition Foundation (1987, 1995); (5) the Danish Nutrition Council Report by Stender et al. (1994, 1995); (6) the FAO/WHO...
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II. FORMS AND SOURCES OF DIETARY ISOMERIC FATTY ACIDS

A. FORMS OF DIETARY ISOMERIC FATTY ACIDS

The major fatty acid isomers formed in the process of hydrogenation are classified into two types: positional and geometric isomers (Dutton, 1979). The term isomeric fat refers to both these types as well as to minor amounts of other fatty acids found in hydrogenated fat. Positional isomers are formed in the hydrogenation process when double bonds shift from their original position in the unprocessed oil to other positions in the molecule. For example, fatty acids containing double bonds at the ∆9 and ∆12 positions are changed to isomeric forms containing double bonds ranging from positions ∆4 to ∆16 (Elson et al., 1981; Marchand, 1982), with the greatest concentration clustered in the vicinity of the original double bond (Scholfield et al., 1967; Carpenter and Slover, 1973; Parodi, 1976a; Emken, 1981; Sampugna et al., 1982). Geometric isomers or cis/trans-isomers are formed when the “naturally” occurring cis-double bonds in vegetable oils are isomerized to the more thermodynamically stable trans-conformation; for example, cis-9-octadecenoic acid or oleic acid is transformed into trans-9-octadecenoic acid or elaidic acid (Figure 15.1). Trans-fatty acids have a higher melting point than the corresponding cis fatty acids and thus contribute to the hardness of
partially hydrogenated fat. Fatty acids containing a cis-double bond have a “bent” structure, whereas those containing a trans-double bond are more linear and thus resemble a saturated fatty acid rather than an unsaturated one. Because of their similarities in conformation, some investigators (Beare-Rogers et al., 1979; Enig et al., 1990b) believe that the sum of the trans- and saturated fatty acids is the physiologically meaningful value and have expressed their data as such. Enig et al. (1990b) term this sum “saturated-equivalents” and report that some snack and fast food items such as cheese corn chips and pizza crust contain as much as 60%-70% of the fatty acids as saturated-equivalents. The composition of the hydrogenated fat depends in part on the composition of the original oil.

If soybean oil and other vegetable oils are used as the source oil, then the hydrogenated product contains primarily isomers of octadecenoic acid (18:1), although much smaller amounts of isomeric fatty acids with shorter chain lengths are formed in some hydrogenated fats (Heckers and Melcher, 1978). If marine oil is used as the raw material, then the hydrogenated fat can contain isomers of fatty acids with chain lengths of 20–22 carbons (Hølmer and Aaes-Jørgensen, 1969; Beare-Rogers, 1983b). In addition to the positional and geometrical isomers that are present in hydrogenated fat, small amounts of other isomeric fatty acids are found in these fats. Cyclic monomers, as well as intra molecular linear dimers, are known to be present (FAO, 1980). These minor components, however, have not been well studied.
B. SOURCES OF DIETARY ISOMERIC FATTY ACIDS

The primary source of isomeric fatty acids in the food supply is commercial hydrogenation of vegetable oils. Emken (1984) estimated that up to 90%-95% of isomeric fatty acids appearing in the U.S. diet at that time was contributed by commercially hydrogenated fat. These hardened fats and oils have been found in margarine, shortening, and frying fats and in various processed foods that contain CC H H (CH 2 ) 7 COOH CH 3 (CH 2 ) 7 cis-9-Octadecenoic acid CC H (CH 2 ) 7 COOH trans-9-Octadecenoic acid H CH 3 (CH 2 ) 7.

FIGURE 15.1 Geometrical isomerism in unsaturated fatty acids.

These fats. Commercial hydrogenation of vegetable oils results in a product that has a higher melting point appropriate for margarine and shortening products, is less susceptible to oxidative rancidity, and has improved flavor stability (Dutton, 1979). By controlling the conditions of the hydrogenation process, the manufacturers can provide the consumer with margarines and shortenings that have the desired consistency and spreadability. At the same time, however, the partial hydrogenation process results in the conversion of some naturally occurring fatty acids to isomeric forms in which both the conformation and position of the double bonds in the fatty acids have been altered. A secondary source of isomeric fatty acids is biohydrogenation, which occurs in ruminant animals as a result of bacterial fermentation in the rumen (Reiser, 1951; Hartman et al., 1954, 1955).

Isomeric fatty acids similar to those formed in commercial hydrogenation are formed by biohydrogenation (Hay and Morrison, 1970). The complex enzyme systems of rumen microorganisms transform...
the monounsaturated and polyunsaturated fatty acids in feedstuffs into more saturated products and into geometric and positional isomers not originally present in the feed. Thus, dairy products and other foods of animal origin contain small amounts of isomeric fatty acids (Hay and Morrison, 1970; Parodi and Dunstan, 1971; Smith et al., 1978; deMan and deMan, 1983; Wolff et al., 1998). Finally, as summarized by Sommerfeld (1983), a number of plant species naturally contain small amounts of trans-unsaturated fatty acids in the seed fats and in the leaves. For example, vegetables such as leeks, peas, spinach, and lettuce contain trans-3-hexadecenoic acid (16:1Δ3t). Rapeseed oil is reported to contain brassidic acid (22:1Δ13t) and gondoic acid (20:1Δ11t) (Turchetto and Lorusso, 1977; Sommerfeld, 1983), but Fogerty et al. (1978) found neither of these fatty acids in rapeseed oil. The other vegetable oils commonly used in margarine and shortening do not naturally contain trans-isomers (Carpenter and Slover, 1973; Lanza et al., 1980; Sommerfeld, 1983).

III. POSITIONAL ISOMERS OF FATTY ACIDS IN FOOD

Hydrogenated vegetable oils, as well as fats from ruminant animals, may contain as many as 20 trans- and cis-positional isomers of octadecenoic acid. The distribution of positional isomers in margarine has been studied by several investigators, including Schofield et al. (1967), Carpenter and Slover (1973), Carpenter et al. (1976), Parodi (1976a), Marchand (1982), Sampugna et al. (1982), Slover et al. (1985), and Caughman et al. (1987). Butter (Parodi, 1976b), milk fat (Hay and
Morrison, 1970), and meat (Wood, 1983) have also been analyzed for positional isomers. In Figure 15.2, the distribution of positional isomers of margarine is compared to that of butter,

using data of Sampugna et al. (1982) for margarine and Parodi (1976b) for butter. The predominant cis-monooene in both butter and margarine is oleic acid (18:1\(\Delta^9\)c). In butter, this isomer comprises 95% of the total cis-octadecenoic acid fraction, and in margarine it typically comprises 60%.

The fatty acid with a cis-double bond at position 11 (18:1\(\Delta^{11}\)c) is the second most prevalent cis octadecenoic isomer in butter (Parodi, 1976b) and in meat (Wood, 1983), but in margarine the cis-positional isomers are more widely distributed among the \(\Delta^8-\Delta^{12}\) positions (see Figure 15.2).

Very small amounts of isomers with double bonds at the other positions are present. In both butter and margarine, trans-octadecenoic acids with double bonds in positions \(\Delta^6-\Delta^{16}\) are present (see Figure 15.2). In butter, the predominant trans-isomer is vaccenic acid, or trans-11 octadecenoic acid (18:1\(\Delta^{11}\)t), with 50%-70% of the trans-octadecenoic acid having a double bond in the \(\Delta^{11}\) position. In a typical margarine, the majority of positional isomers of trans-octadecenoic acid have double bonds at \(\Delta^9-\Delta^{12}\), although the exact distribution of positional isomers varies depending on the conditions of hydrogenation (Allen and Johnston, 1960). This variation can be seen in the five brands of margarine analyzed by Sampugna et al. (1982) (see Figure 15.3). In addition to isomers of octadecenoic acid, cis-isomers of 14:1, 16:1, and 17:1 and trans isomers of 16:1 are present in milk fat (Hay and Morrison, 1970; Wolff, 1994). The distribution of
double bonds in cis- and trans-monoenoic fatty acids from bovine milk fat is illustrated in Table 15.1.

Somewhat similar distributions of trans-positional isomers of octadecenoic acid in milk fats have been reported by other investigators (Parodi, 1976b; Wolff, 1994; Precht and Molkentin, 1995). In hydrogenated soybean oil, the trans-monoenes are almost exclusively isomers of octadecenoic acid. Hydrogenation of vegetable oils to form shortening or margarine results in the conversion of linoleic acid (18:2\(\Delta_9c, 12c\)) to monoenes (Allen and Johnston, 1960). As a result, most of the positional isomers in partially hydrogenated fat are monoenoic fatty acids; however, small amounts of isomeric dienes are also formed. Dienes containing conjugated double bonds are present in hydrogenated fat, and concentrations of these conjugated dienes, ranging from 0.2% to 1.9% of fatty acids in margarine and shortening, have been reported by a number of investigators (Mabrouk and Brown, 1956; Sreenivasan and Brown, 1956; Schofield et al., 1967; Hølmer and Aaes-Jørgensen, 1969; Carpenter and Slover, 1973; Parodi, 1976a; Smith et al., 1978). Animal fat of ruminant origin also contains about 1%-2% of the fatty acids as conjugated dienes (Parodi, 1977). The methylene-interrupted diene system in linoleic acid is crucial to its role as an essential fatty acid. Since the double bonds in linoleic acid can be isomerized during hydrogenation in both conformation and position, enzymatic lipoxygenase activity specific for the cis,cis-methylene interrupted structure is often used as a measure of “physiologically active polyunsaturated fat”
Smith et al., 1978). In comparing butter and margarine, Smith et al. (1978) reported that butter contained 3%-5% and margarine 15%-42% cis,cis-methylene-interrupted fatty acids.

IV. TRANS-ISOMERS OF FATTY ACIDS IN FOODS

In part because of methodological considerations, data exist primarily for the trans-fatty acid isomers rather than the positional isomers of specific food items. In this section, available information on the trans-fatty acid content of foods is summarized. The food items are grouped into four broad categories:

(1) dairy products, meats, and animal fats; (2) margarines, shortenings, and vegetable oils; (3) fast foods and processed foods; and (4) human milk and infant foods.

| Co | m | p | s | i | t | i | o | n | , | % | 5 | 0 | 6 | 0.2 | 0.2 | 0.2 | 0.9 | 3.6 | 63.6 | 7.2 | 13.6 | 14.5 | 9.1 | 4.5 | 2.7 | 3.6 | 1.7 | 3.3 | 9.7 | 17.3 | 21.7 | 20.3 | 14 | 9.7 | 5 | 3 | 2.3 | 0.2 Butter Positional isomers of 18:1cis
| (a) | (b) |

(c) (d) Butter Positional isomers of 18:1trans Margarine
Positional isomers of 18:1cis Margarine Positional isomers of 18:1trans

<table>
<thead>
<tr>
<th>Double bond position</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition, %</td>
<td>5</td>
<td>0</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
</tr>
</tbody>
</table>

TABLE 15.1

Distribution of Double Bonds in Cis- and Trans-Monoenoic Fatty Acids from Bovine Milk Fat (Cream) a

<table>
<thead>
<tr>
<th>Position of Double Bond</th>
<th>Cis-Isomers</th>
<th>Trans-Isomers</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:1</td>
<td>1.0 tr</td>
<td>2.2 6 0.8 1.3 3.4 7.8 1.0 7 0.9 5.6</td>
</tr>
<tr>
<td>16:1</td>
<td>18:1 15 1.0 tr 2.2 6 0.8 1.3 3.4 7.8 1.0 7 0.9 5.6</td>
<td></td>
</tr>
<tr>
<td>17:1</td>
<td>18:1 15 1.0 tr 2.2 6 0.8 1.3 3.4 7.8 1.0 7 0.9 5.6</td>
<td></td>
</tr>
<tr>
<td>18:1</td>
<td>18:1 15 1.0 tr 2.2 6 0.8 1.3 3.4 7.8 1.0 7 0.9 5.6</td>
<td></td>
</tr>
<tr>
<td>19:1</td>
<td>18:1 15 1.0 tr 2.2 6 0.8 1.3 3.4 7.8 1.0 7 0.9 5.6</td>
<td></td>
</tr>
<tr>
<td>20:1</td>
<td>18:1 15 1.0 tr 2.2 6 0.8 1.3 3.4 7.8 1.0 7 0.9 5.6</td>
<td></td>
</tr>
</tbody>
</table>

a Values expressed as wt.%. tr = trace. Source: Adapted from data of Hay, J.D., and Morrison, W.R. (1970). Biochim. Biophys. Acta 202: 237-243. It is important to recognize from the outset the limitations of such data, particularly with regard to incorporation of these values into tables of food composition. First, values of trans-fatty acids determined prior to 1970 using older methodology, that is, before capillary gas chromatography, are considered to be less accurate (Brisson, 1981; Lanza and Slover, 1981). Recently, various methods for analyzing trans-fatty acids have been compared by Ratnayake (1998). Second, there is tremendous variability in values for any one type of food item. As a result, average values have limited...
use in food composition tables. Using minimum and maximum values for trans-fatty acids within a given food item (Innis et al., 1999) have shown that estimates of the trans-fatty acid content of the same diet can vary from a low of 1.4–25.4 g/day. Third, values for the trans-fatty acid content of food items presented as percentages of fatty acids without coupling these values to the fat content of food are also of somewhat limited use in food composition tables, because the gram quantity of trans-isomers in a serving of food cannot be determined. Fourth, products are constantly being reformulated, making it difficult to build up a reliable database. Industry responds to economic pressures and to public concerns over current health issues, and as a result changes the conditions of processing as well as the type and amount of fat used in various products. This has been particularly true recently as legislation that limits the content of industrially processed trans-fatty acids in the food has been passed in countries such as Denmark and as food-labeling regulations requiring trans-fat content have been implemented in countries such as the United States (Ratnayake and Zehaluk, 2005; Leth et al, 2006; Moss, 2006). Thus, the composition of the product may have changed by the time values are ready to be incorporated into food composition tables. With these limitations in mind, available data on the trans-fatty acid content of various food items are summarized here.

A. TRANS-ISOMERS OF FATTY ACIDS IN DAIRY PRODUCTS, MEATS, AND ANIMAL FATS
Foods such as butter, milk, beef, and lamb are derived from ruminant animals. Trans-fatty acids are formed as a result of biohydrogenation in the rumen of these animals, and thus dairy products and meats contain small but significant quantities of isomeric fatty acids (Wolff et al., 1998).

Vaccenic acid (18:1\text{\(\Delta\)11t}) is the predominant trans-isomer in these foods, although smaller amounts of other trans-monoenes are found in the hexadecenoic (16:1) and octadecenoic (18:1) fractions of milk (Hay and Morrison, 1970) and meat (Wood, 1983). In fats of ruminant origin, the trans-fatty acids are located in the 1- and 3-positions of the triacylglycerol, with no measurable amounts at the 2-position (Woodrow and deMan, 1968). The presence of CLA in meat and dairy products is of particular interest because of its reported anticarcinogenic effects as well as other possible beneficial biological effects. These biological effects of CLA and its occurrence in food have been reviewed recently by Banni and Martin (1998).

Animal products are the principal dietary sources of CLA, although conjugated dienes are also found in low concentrations in plant oils and partially hydrogenated oils (Chin et al., 1992). The major conjugated diene in fats of ruminant origin is 9-cis,11-trans-octadecadienoic acid, with this isomer comprising 80%-90% of the total CLA in meat and dairy products (Chin et al., 1992; Parodi, 1994). Dairy products are the richest dietary sources of CLA. The content of CLA in milk fat varies depending on pasture conditions and may contain up to 30 mg/g fat (Parodi, 1994). Chin et al. (1992) reported the CLA content of a variety of U.S. foods. For homogenized milk, condensed milk,
and cultured buttermilk (three samples each), the total CLA content was 5.5 ± 0.30, 7.0 ± 0.29, and 5.4 ± 0.16 mg/g of fat, respectively. Similar values were reported by Lin et al. (1995), with values of

CLA for K uid milk products ranging from 3.4 to 6.4 mg/g of fat. Yogurt contains CLA at approximately 4 mg/g of fat (Chin et al., 1992; Lin et al., 1995). Cheeses vary in CLA content, with Lin et al. (1995) reporting 3.59–7.96 and Chin et al. (1992) reporting 2.9–7.1 mg/g of fat. Banni et al. (1996) reported greater values for CLA in Italian dairy products with cow milk at 7.10, sheep milk at 11.72–29.68, yogurt at 7.98, and cheeses at 8.65–24.19 mg/g of fat. Meats of ruminant origin contain more CLA than meats from nonruminant animals. Chin et al. (1992) reported values of 2.7, 2.9, 3.3, 3.8, 4.3, and 5.6 mg/g of fat for the CLA content of veal, beef round, beef franks, smoked beef sausage, fresh ground beef, and lamb, respectively, in contrast to values for pork (0.6 mg/g of fat) and chicken (0.9 mg/g of fat). Fresh ground turkey contained 0.25 mg/g of fat, whereas seafood contained 0.3–0.6 mg/g.

B. MILK FAT AND BUTTER

Values for the trans-fatty acid content of milk fat and butter range from 1.75% (Ellis et al., 2006) to 8.6% (Woodrow and deMan, 1968) of total fatty acids (Table 15.2). In general, butter and milk fat appear to contain approximately 3%–6% trans-fatty acids (Table 15.2). The value of 0.65% triglyceride reported by Huang et al. (2006) appears to be much less than values reported by others. Some of the variations seen in reported values can also be attributed to seasonable variation.
Butter is reported to contain the lowest amounts of trans-fatty acids (4.3%-4.9%) in winter and the highest values (6.5%-7.6%) in spring and summer (Parodi and Dunstan, 1971; deMan and deMan, 1983). This seasonal variation is believed to be due to differences in the feedstuffs, with spring and summer pastures containing more polyunsaturated fatty acids than the winter feed supply.

Henninger and Ulberth (1994) have reported a detailed analysis of the trans-fatty acid content of butter samples collected from Austrian dairies at monthly intervals. Consistent with earlier reports, greater values for trans-fatty acids were observed for samples collected during pasture feeding in the summer compared to samples collected during winter months. The values for 18:1t were greater if argentation thin-layer chromatography combined with gas chromatography was used rather than direct gas chromatography; however, the variation due to methodology was not as great as that due to seasonal variation. Similar variation in French butters collected at various times of the year has been reported by Wolff et al. (1995). The trans-fatty acid values for cheeses and yogurt are shown in Table 15.2a. Most cheeses contain 3%-6% of total fatty acids as trans-fatty acids. As one would expect, the trans-content of cheeses, including those made from goat and ewe milk, reflects seasonal variation in the type of feed available (Wolff, 1995).

### Table 15.2

<table>
<thead>
<tr>
<th>Reference Food Item</th>
<th>Trans-Fatty Acid a (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butter</td>
<td></td>
</tr>
</tbody>
</table>
Woodrow and deMan (1968) Milk fat 8.6

Hay and Morrison (1970) Buttermilk fat 6.0 Cream fat 3.2

Parodi and Dunstan (1971) Butter (116 Australian samples) 6.0 b

Smith et al. (1978) Milk fat c (5 U.S. brands) 1.9 d

deMan and deMan (1983) Butter (Canadian) 5.7 e

Enig et al. (1983) Butter (3 U.S. brands) 3.4

Ball et al. (1993) Butter, semisoft (New Zealand) 3.2 f

Butter, clarified (New Zealand) 1.8 f

Boatella et al. (1993a) Butter (15 Spanish samples) 5.3 ± 0.6 g,h Milk fat (34 Spanish samples) 3.5 ± 0.7 g,h

Pfalzgraf et al. (1993) Milk fat (15 German samples) 3.64 ± 1.15 Butter (5 German samples) 4.12 ± 2.37

Henninger and Ulberth (1994) Butter (Austrian samples) 4.25 ± 1.2 h,i

Michels and Sacks (1995) Butter (U.S. samples) 3.4 j

USDA (1995) Milk fat (U.S. composite sample, April) 2.94 (U.S. composite sample, July) 3.39 (2 U.S. composite samples) 2.75

Wolff et al. (1995) Butter (12 French samples, January) 2.37 ± 0.27 h,k (12 French samples, May/June) 4.28 ± 0.47 h,k

Fernandez San Juan (1996) Milk fat (25 Spanish samples) 3.4 ± 0.4

Precht and Molkentin (1996) Milk fat (100 German samples) 3.83 ± 1.34 h,k (Belgium sample) 3.19 h,k (4 Danish samples) 4.21 ± 0.60 h,k (10 Spanish samples) 4.04 ± 0.30 h,k (10 French samples) 4.47 ± 0.92 h,k (4 Greek samples) 4.01 ± 0.15 h,k (12 Italian samples) 4.14 ± 1.30 h,k (22 Irish samples) 5.91 ± 0.92 h,k (Luxembourg sample) 3.51 h,k (24 Dutch samples) 4.09 ± 0.91 h,k (23 United Kingdom samples) 4.78 ± 0.91 h,k

Lake et al. (1996) Butter (5 New Zealand samples) 6.4 ± 1.02 h
Richardson et al. (1997) Butter (New Zealand samples) 6.72
Aro et al. (1998a) Milk fat (Belgium sample) 4.68
(Danish sample) 4.07 (Finland sample) 3.19 (French sample) 5.09 (German sample) 3.55 (Greek sample) 3.90
(Iceland sample) 5.24 (Italian sample) 4.37 (Dutch sample) 4.41 (Norway sample) 3.72 (Portugal sample) 4.67 (Spanish sample) 4.73 (United Kingdom sample) 3.81
Aro et al. (1998a) Butter (Belgium sample) 5.43 (Danish sample) 4.51
(Finnland sample) 4.01 Continued

C. MEATS

Data on the trans-fatty acid content of meats are summarized in Table 15.3. The most extensive early isomeric fatty acid analysis of meats was performed in the laboratory of Slover (Slover and Lanza, 1979; Lanza et al., 1980; Lanza and Slover, 1981; Slover, 1985; Slover et al., 1987a,b), although values for trans-fatty acids in meats have also been reported by Wood (1983). Since 1990, values for the trans-fatty acid content of meats and meat products have been reported in the United States (Litin and Sacks, 1993; USDA, 1995; Huang et al., 2006), Europe (Aro et al., 1998a), Spain (Boatella et al., 1993a; Fernandez San Juan, 1996), Canada (Ratnayake et al., 1993; Innis et al., 1999; Ratnayake and Zehaluk, 2005), France (Wolff, 1995), Costa Rica (Monge-Rojas et al., 2005), and New Zealand (Richardson, 1997), and are in general agreement with earlier values.

TABLE 15.2
(Continued)

Reference Food Item Trans-Fatty Acid a (%) (French sample) 5.98 (German sample) 4.04 (Greek sample) 4.77
Iceland sample) 4.36 (Italian sample) 4.18 (Dutch sample) 6.15 (Norway sample) 4.84 (Swedish sample) 4.43

Collomb et al. (2002) Milk fat (24 Switzerland Highlands samples) 8.44 ± 0.73 h,m

Collomb et al. (2002) Milk fat (12 Switzerland Mountains samples) 6.44 ± 0.48 h,m

Collomb et al. (2002) Milk fat (12 Switzerland Lowlands samples) 4.55 ± 0.47 h,m

Monge-Rojas et al. (2005) Butter (Costa Rican samples) 3.49 g,n

Ratnayake and Zehaluk (2005) Bovine milk (Canadian sample) 4.3

Ratnayake and Zehaluk (2005) Butter (Canadian sample) 5.7

Ellis et al. (2006) Milk fat, conventional (19 United Kingdom samples) 1.75 ± 1.09 h,k

Ellis et al. (2006) Milk fat, organic (12 United Kingdom samples) 2.06 ± 0.96 h,k

Huang et al. (2006) Butter (U.S. sample) 0.65 ± 0.05 h,o

a Trans-fatty acids are expressed as percentage of total fatty acids.

b Range = 4.27%-7.64% with minimum values in the winter and maximum values in spring/summer.

c Fat content = 81%.

d 1.9% by GC/TLC method, 4.0% by AOCS method.

e 4.9% in winter; 6.5% in summer.

f 18:1t + 18:2t.

g 16:1t + 18:1t + 18:2t.

h Mean ± SD.

i Value includes 16:1t but not conjugated linoleic acid; range = 2.26-6.52 g/100 g milk fat, with high trans-fatty acid
content reported for pasture feeding in the summer months.

\[ \text{j} \quad 2.70 \text{ g trans per 81.11 g fat.} \]

\[ \text{k} \quad 18:1t \text{ only.} \]

\[ \text{l} \quad \text{Data expressed as percentage of fatty acid methyl esters.} \]

\[ \text{m} \quad \text{Without CLA t 12.} \]

\[ \text{n} \quad \text{Trans-fatty acids expressed as g/100 g food.} \]

\[ \text{o} \quad \text{Data expressed as percentage of corresponding triglyceride.} \]

**TABLE 15.2a Trans-Fatty Acid Content of Cheese and Yogurt (25) Reference Food Item a Trans-Fatty Acids (%) b (g/100 g Food) Pfalzgraf et al. (1993) German cheeses Regular (22) 3.01 ± 1.03 Goat (2) 3.15 ± 1.06 Ewe (3) 5.60 ± 1.66 Ball et al. (1993) New Zealand cheeses Cottage cheese 0.90 Cream cheese (2) 1.2–2.4 Wolff (1995) French cheeses Goat (8) 2.68 ± 0.68 Ewe (7) 1.53 ± 1.11 USDA (1995) U.S. cheeses Cheddar 2.54 0.59 Processed (6) 2.41–3.49 0.31–0.57 Banni et al. (1996) Italian cheeses Pecorino 4.99 ± 2.89 c Ricotta 9.10 ± 0.33 c Parmesan 3.22 ± 0.66 c Swiss cheese 3.70 ± 0.74 c Boulous et al. (1996) Greek feta cheese 1.40 Pfalzgraf et al. (1993) German yogurt (1) 3.3 USDA (1995) U.S., low-fat yogurt (2) 2.39–3.18 0.01–0.02 Banni et al. (1996) Italian yogurt 4.94 ± 0.59 Aro et al. (1998a) d Belgium cheese 5.00 Danish cheese 5.24 Finland cheese 3.92 French cheese 3.85 German cheese 3.91 Greek cheese 4.65 Iceland cheese 3.59 Italian cheese 4.45 Dutch cheese 4.37 Norway cheese 3.83 Portugal cheese 5.42 Spanish cheese 5.68 U.K. cheese 4.52 Monge-Rojas et al. (2005) e Costa Rican cheese Fresh 1.31 Cream cheese 1.96 Ratnayake and Zehaluk (2005) Canadian cheese Cheddar 6.6 Cottage 5.5 Processed 5.9 Yogurt 5.4 a Number of samples analyzed appears in parentheses following food item. b Trans-fatty acids are expressed as percent of total fatty acids. c 18:1t. d Data expressed as percentage of fatty acid methyl esters. e 16:1t + 18:1t + 18:2t. **TABLE 15.3 Trans-Fatty Acid Content of Meats Reference and Food Item a Fat (wt.%) Trans-Fatty Acids (%) b (g/100 g Food) Slover and Lanza (1979) Baby food Strained beef liver (1) 4.10 1.90 0.05 Strained lamb broth (1) 9.33 7.57 0.33 Lanza et al. (1980) Beef, raw (1) 36.57 4.88 1.61 c Cooked (1) 37.05 4.00 1.69 c Liver lipid (1) 6.15 0.91 0.04 Lanza and Slover (1981) Beef, rib roast, separable lean (1) 5.46 4.21 0.23 Wood (1983) d Beef, lean (3) 3.2 2.9 0.09 Bologna (3 brands) 26.5 0.17 Luncheon meat (3 brands) 23.8 0.002 Hot dogs (3 brands) 27.2 0.55 Vienna sausage (3 brands) 27.3 0.37 Slover
Beef, retail cuts, lean portion

Raw (111) 6.46
Cooked (109) 11.03 3.05 Slover et al. (1987a) e

Beef, 14 retail cuts, lean portion

Raw (269) 7.37 3.20 Slover et al. (1987b) Pork, 7 retail cuts

Raw (7) 7.60
Cooked (7) 14.23 0.3 Boatella et al. (1993a) Beef

(45 Spanish) 8.5 ± 2.7 Pork (35 Spanish) 0.6 ± 1.0 Meat

products (46 Spanish) 0.5 ± 0.3 Litin and Sacks (1993)

Beef (United States) 0.63 Pork (United States) 0.07

Chicken (United States) 0.07 Pfalzgraf et al. (1993) Beef

(4 German) 2.73 ± 0.56 Veal (3 German) 1.37 ± 0.42 Lamb

(3 German) 7.53 ± 1.14 Mutton (3 German) 9.30 ± 1.21 Pork

(German) Filet 0.2 Bacon 0.4 TABLE 15.3 (Continued)

Reference and Food Item a Fat (wt.%)

Trans-Fatty Acids (%)

b (g/100 g Food) Ham, cooked 0.2 Ham, smoked 0.5

Poultry (German) Rooster 0.5 Duck 0.5 Turkey 1.4

Wild pigeon 0.2 Sausages (22 German) 0.68 ± 0.67 Ratnayake

et al. (1993) Meat patty (Canadian) 16.5 3.5 USDA (1995)

Beef Ground, raw (2 United States) 21.57 4.50 0.06

Ground, cooked (2 United States) 19.15 5.10 0.87 Turkey

Raw (2 United States) 3.59 2.75 0.09 Burger, cooked (2

United States) 17.03 3.63 0.54 Ground, raw (10 United

States) 8.57 3.58 0.27 Bologna Beef (2 United States)

26.41 5.17 1.30 Pork (2 United States) 28.71 0.67 0.19

Sausages Frankfurter (4 United States) 29.38 3.21 0.90

Kielbasa, beef (United States) 29.39 4.55 1.27 Sausage

links (United States) 28.90 0.35 0.09 Pork (United

States) 28.26 0.41 0.11 Pepperoni (United States) 41.34

0.93 0.36 Wolff (1995) Beef (10 French) 1.95 ± 0.94 f

Fernandez San Juan (1996) Sausages (40 Spanish) 26.5 ± 5.8

0.7 ± 0.5 Richardson et al. (1997) Meat patty (New

Zealand) 24.64 4.32 Luncheon meat (New Zealand) 13.05 4.98

Aro et al. (1998a) g Beef (Europe) 3.3–21.5 3.02–9.52

Lamb/mutton (Europe) 4.4–10.9 4.32–9.19 Pork (Europe)

2.2–32.0 0.19–0.86 Chicken (Europe) 1.8–18.8 0.24–1.71

Turkey (Europe) 1.8–11.6 0.31–1.27 Sausages (Europe)

Highest in trans 13.8–40.5 0.36–5.30 Lowest in trans

14.7–39.5 0.25–1.01 Continued Lipids in the separable lean

of raw and cooked beef were analyzed by Slover et al.

(1987a). The

content of trans-monoene ranged from a minimum value of

1.3% in top round steak, choice grade to

a maximum value of 4.4% in rib roast, large end, Good (now
called Select) grade. Average content

of trans-fatty acids in all 14 cuts of lean, raw beef was

3.2% of total fatty acids. In addition to trans

monoenes, small amounts of trans-dienes (18:2Δ9t, 12t and
18:2Δ9c, 12t) were also found, usually in amounts less than 0.2%. Moisture loss and other factors during cooking resulted in a slightly higher concentration of trans-fatty acids in the cooked samples than in the raw sample (Slover, 1985). The average value of 3.2% of fatty acids as trans-monoenes in lean beef is in relatively good agreement with the value of 2.9% calculated from the data of Wood (1983). In addition to lean beef, processed meats were analyzed by Wood (1983). In part because of their high fat content, bologna, hot dogs, and Vienna sausage contained more trans-fatty acids per 100 g of food than the lean raw beef. On the other hand, beef liver appears to contain much smaller amounts of trans-isomers than raw or cooked beef samples (Lanza et al., 1980). Cuts of pork contain 0.2%-0.3% of the fatty acids as trans-monoene (Slover et al., 1987b), presumably derived from milk products in diets fed to pigs during the early weeks of life (Sommerfeld, 1983). Slover and Lanza (1979) reported the trans-fatty acid content of baby foods, with strained beef liver containing 1.9% and strained lamb broth 7.6% of total fatty acids as trans-isomers. 

TABLE 15.3 (Continued)

Reference and Food Item a Fat (wt.%) Trans-Fatty Acids (%) b (g/100 g Food) Innis et al. (1999) Meat patty (4 Canada) 16.4 6.8 1.1 Breaded chicken (8 Canada) 13.4 27.4 3.7 Ratnayake and Zehaluk (2005) Beef, steak (Canada) 8.0 3.2 Beef, roast (Canada) 5.9 1.9 Beef, ground (Canada) 8.6 3.9 Veal (Canada) 1.7 2.9 Lamb (Canada) 6.0 8.1 Organ meat (Canada) 4.6 3.4 Pork (Canada) 5.7 0.5 Chicken (Canada) 2.4 2.5 Monge-Rojas et al. (2005) h Red meat (Costa Rica) 0.79 Huang et al. (2006) i Chicken patties (United States) 0.93 ± 0.4 a Number of samples/brands analyzed appears in parentheses following food item. b Percentage of total fatty acids. c Values presented as g/100 g dry weight. d Calculated from data for neutral lipids and phospholipids. e Larger database than reported in Slover (1985). f Represents total trans-18:1 content. g Values presented as range; samples from 14 European countries. Data expressed
as percentage of fatty acid methyl esters. h 16:1t + 18:1t + 18:2t. i Data expressed as percentage of corresponding triglyceride.

D. ANIMAL FATS

Beef fat is reported to contain 1.8%–6.55% trans-fatty acids (Table 15.4). Lamb fat contains more trans-fatty acids than beef fat (Enig et al., 1983; Ball et al., 1993; Wolff, 1995; Bayard and Wolff, 1996), whereas lard, because it is derived from a nonruminant source, contains much less trans-fatty acid (Enig et al., 1983; Slover et al., 1987b; Boatella et al., 1993a; Mansour and Sinclair, 1993; USDA, 1995). Australian drippings are reported by Mansour and Sinclair (1993) to contain trans fatty acids at 4.56% of total fatty acids. Trans-fatty acid values for turkey fat and chicken fat are reported to be 3.91 g/100 g of food and 0.75 g/100 g of food, respectively (USDA, 1995).

E. TRANS-ISOMERS OF FATTY ACIDS IN MARGARINES, SHORTENING, AND VEGETABLE OILS

Hydrogenated vegetable oils are the source of most of the trans-fatty acids in the North American diet. The 6-8 billion pounds of hydrogenated vegetable oil produced in the United States per year is used in the production of margarines, shortenings, and salad/cooking oils. The trans-fatty acid content of these products varies from small amounts in lightly hydrogenated salad oils—for example, 5% of total fatty acids as reported by Carpenter et al. (1976) (see Table 15.8)—to typical values of 40% or more in commercial frying fats (Smith et al., 1986) (see Table 15.7). In margarines and other hydrogenated products, trans-fatty acids appear to be concentrated in the 2-position of the triglyceride. In some of the 10
margarine samples analyzed by Carpenter and Slover (1973), there was a greater percentage of trans-monoene at the 2-position than in the total.

TABLE 15.4

Trans-Fatty Acid Content of Animal Fats

<table>
<thead>
<tr>
<th>Reference Food Item</th>
<th>Trans-Fatty Acids (%)</th>
<th>g/100 g Food</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parodi (1976a) Animal fat (4 Australia)</td>
<td>7.8</td>
<td></td>
</tr>
<tr>
<td>Slover and Lanza (1979) Beef fat (7 United States)</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>Enig et al. (1983) Beef fat (1 United States)</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Slover (1985) Beef fat 70.89% fat, raw (12 United States) 6.55 70.32% fat, braised (6 United States) 5.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enig et al. (1983) Lamb fat (1 United States)</td>
<td>6.6</td>
<td></td>
</tr>
<tr>
<td>Enig et al. (1983) Lard (1 United States)</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Slover et al. (1987b) Pork fat, separable (6 United States)</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Ball et al. (1993) Beef fat (New Zealand)</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Boatella et al. (1993a) Lard (35 Spanish)</td>
<td>0.7 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>Mansour and Sinclair (1993) Lard (Australia)</td>
<td>0.73 Drippings (Australia) 4.56</td>
<td></td>
</tr>
<tr>
<td>Pfalzgraf et al. (1993) Beef tallow (Germany)</td>
<td>1.9 Lard (Germany) 0.4</td>
<td></td>
</tr>
<tr>
<td>USDA (1995) Lard (3 United States) 1.00 1.07 Turkey, visible fat (1 United States) 3.91 2.54 Chicken broiler fat (1 United States) 1.15 0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wolff (1995) Beef tallow (2 French)</td>
<td>4.6 c</td>
<td></td>
</tr>
<tr>
<td>Bayard and Wolff (1996) Repele 1 ned beef tallow (10 French)</td>
<td>4.91 ± 0.87 c</td>
<td></td>
</tr>
</tbody>
</table>

a Number of samples analyzed appears in parentheses following food item.

b Percent of total fatty acids.
c Value for 18:1t content.

fatty acids in the triglyceride. This was probably due to the preferential placement of polyunsaturated fat (e.g., linoleic acid) at the 2-position in the original vegetable oil. In the process of partial hydrogenation, some of these polyunsaturated fatty acids at the 2-position would be converted to trans monoenoates. In contrast, as mentioned previously in this chapter, animal fats contain trans-fatty acids preferentially at the 1- and 3-positions of the triglyceride (Woodrow and deMan, 1968).

F. MARGARINES

The trans-fatty acid content of stick or hard margarines is greater than that of soft or tub margarines.

Both Enig et al. (1983) and Slover et al. (1985) reported that stick margarines, on the average, contained 24% of the fatty acids as trans-isomers, with minimum values of 16%-17% and maximum values at 35%-36%. In contrast, tub or soft margarines collected at the same time as the stick margarines generally contained 14%-18% of fatty acids as trans-fatty acids with a range of 10%-30% (Table 15.5). Diet margarines analyzed in the 1980s in the United States were similar to soft margarines, containing about 15% trans-fatty acids (Enig et al., 1983). The value of 23% used by Enig et al. (1990a) in calculating per capita consumption of trans-fatty acids was based on tub margarines comprising 20% of the total margarine market. This value of 23% appears to be a reasonable estimate of the amount of trans-fatty acids in U.S. margarines at that time. Margarines and table spreads, like other foods, have recently undergone reformulation to reduce
the trans-fatty acid content. For example, this change for German margarines has been documented by Precht and Molkentin (2000) who reported a decrease in the trans-fatty acid content of margarine from 22% of total fatty acids in 1994 to 5% in 1999 (Table 15.5). Similarly, Henninger and Ulberth (1996) reported that stick and tub margarines collected in 1995 had decreased to about half of their 1991/1992 values (Table 15.5). Aro et al. (1998b) reported differences in the trans-fatty acid content of margarines dependent on the country in which they were collected. Soft table margarines collected in Iceland, Norway, and the United Kingdom had the greatest trans-fatty acid content with values ranging from 13.0% to 16.5% of total fatty acid methyl esters. Margarines collected in Italy, Germany, Finland, and Greece had a trans-fatty acid content of 5.1%, 4.8%, 3.2%, and 2.9% of total fatty acids, respectively; whereas margarines from other countries (Portugal, The Netherlands, Belgium, Denmark, France, Spain, and Sweden) contained less than 2% of the total fatty acids as trans-fatty acids. Other countries, such as the United States and Canada, have lagged behind Europe in making significant decreases in the trans-fatty acid content of margarines (Table 15.5). With the recent advent of trans-fat labeling of foods (Moss, 2006), rapid change in the trans-fatty acid content of margarines is occurring in the United States. These changes, however, have not been documented in a systematic manner. Most of the trans-fatty acids in margarine and other hydrogenated fats are monoenoic (18:1t) isomers; however, the trans-dienes (18:2t,c; 18:2c,t; and 18:2t,t) are found in much smaller amounts.
Kinsella et al. (1981) reviewed the literature on possible physiological effects of high levels of trans,trans-octadecadienoate (18:2t,t) in the diet. Concern was expressed about this particular isomer because of its potential interference with the metabolism of the essential fatty acid linoleic acid (18:2Δ9c, 12c). Currently available data on the composition of margarine (Table 15.6) would indicate that hydrogenated fat contains small amounts of trans,trans-octadecadienoate and at the same time sufficient quantities of the all-cis-isomer (linoleate). Enig et al. (1983) reported maximum values of 5% for the sum of trans-dienes (18:2i)* in 40 margarine samples. Linoleic acid composed, on the average 26%-35%, of total fatty acids in these margarine samples (Table 15.6). Total trans-isomers of ∆9,12-octadecadienoate (18:2t,c, 18:2c,t, and 18:2t,t) in margarines analyzed by Slover et al. (1985) ranged from 0.17% to 11.6%, with an average of 1.9%. The trans,trans-∆9,12-octadecadienoate (18:2t,t) made up only 0.19% of total fatty acids, with a maximal value of 1.5% in these margarine samples. Only four of the margarines tested by Slover et al. (1985) contained the term 18:2i or “isomeric” octadecadienoic acid is defined as the sum of 18:2c,t, 18:2t,c, and 18:2t,t.

**TABLE 15.5**

<table>
<thead>
<tr>
<th>Reference Food Item a,b</th>
<th>Trans-Fatty Acids % Fatty Acids</th>
<th>g/100 g Food</th>
<th>Min</th>
<th>Max</th>
<th>Avg ± SD</th>
<th>Min</th>
<th>Max</th>
<th>Avg ± SD</th>
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<tbody>
<tr>
<td>Carpenter and Slover (1973) U.S. margarines Stick (6)</td>
<td>- 36.0 25.7</td>
<td>c Tub (4)</td>
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<td>Reference</td>
<td>Food Item</td>
<td>a,b Trans-Fatty Acids</td>
<td>% Fatty Acids</td>
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<tr>
<td></td>
<td>g/100 g Food</td>
<td>Min</td>
<td>Max</td>
<td>Avg ± SD</td>
<td>Min</td>
<td>Max</td>
<td>Avg ± SD</td>
<td></td>
</tr>
</tbody>
</table>

Weihrauch et al. (1977) U.S. margarines Stick and brick (17) 9.9 28.7 21.7 Tub (13) 10.5 21.4 14.2

Smith et al. (1978) U.S. margarines (5) 13.6 23.3 17.8

Enig et al. (1983) U.S. margarines Stick (24) 17.4 36.0 24.2 Tub (13) 10.6 21.3 14.4 Diet (3) 12.7 16.9 15.3

Slover et al. (1985) U.S. margarines Stick (57) 16.1 34.8 23.7 Block — — 21.7 Tub (26) 11.7 29.8 17.7 Stick, lard (1) — — 3.9

Enig et al. (1990a) Weighted average for all U.S. margarine d 23.0

Litin and Sacks (1993) U.S. margarines Soft 3.0 10.2 5.7 Stick 7.9 19.8 13.2

Michels and Sacks (1995) U.S. margarines Stick, corn oil 18.6 Tub, corn oil 9.0 Blend, light 2.0


Ali et al. (1996) U.S. fat-free margarine 1.52 0.04

Satchithanandam et al. (2004) U.S. margarines Soybean oil (2) 15.6 Soft, soybean oil (2) 27.7 Spreadable sticks, 60% soybean oil (2) 19.0 Spread, 65% soybean oil (2) 15.1 Spread, 70% soybean oil (2) 16.4 Corn oil (2) 14.9

Huang et al. (2006) e U.S. margarines 19.13 ± 0.93 Continued TABLE 15.5 (Continued)
Mozaffarian et al. (2006) U.S. margarines
Hard (stick) 15
23 Soft (tub) 5 14

Baere-Rogers et al.
(1979) Canadian margarines (8) 12.0 64.8 30.3

Sahasrabudhe and Kurian (1979) Canadian margarines Stick, vegetable oil
(33) 27.2 32.9 30.7 Soft, vegetable oil (49) 8.7 28.5 15.0
Stick, animal fat (6) f 4.2 25.3 18.4

30.0 Tub (30) 9.4 27.4 15.6

Ratnayake et al. (1991) Canadian margarines Stick, soybean oil (3) 30.4 49.9 38.8 ± 10.0 Stick, vegetable oil (5)
25.6 40.2 33.42 ± 5.78 Stick, may contain palm oil (7)
32.8 40.6 35.2 ± 2.6 Stick, corn oil (1) 28.2 Stick, veg.
ioil/animal fat (1) 42.2 Stick, unspecifed (2) 20.9 28.8
24.9 ± 5.6 Tub, soybean oil (13) 12.4 27.3 18.7 ± 3.9
Tub, vegetable oil (10) 22.1 35.2 26.4 ± 3.8 Tub, may
contain palm oil (2) 19.5 21.3 20.40 ± 1.27 Tub, corn
oil (3) 10.1 25.3 16.8 ± 7.8 Tub, sunflower oil (2) — 14.3
7.15 Tub, olive oil (1) 19.4

Ratnayake and Pelletier
(1992) Canadian margarines Hard, 6 types (19) 34.2 g
Soft, 6 types (31) 21.3 g

Innis et al. (1999) Canadian margarines Hard (14) 31.1
44.6 39.8 Soft (14) 1.1 44.4 16.8

Elias et al. (2002) Canadian margarines Stick (14) 31.1
44.6 39.8 ± 4.5 Soft (16) 1.0 44.4 16.8 ± 11.2

Monge-Rojas et al.
(2005) Costa Rican margarines 6.32 h

Leigheld (1986) i English margarines Low, <10% PUFA (4)
3.7 21.4 11.5 Medium, 10%-30% PUFA (10) 5.5 14.9 11.1

High, PUFA (9) 4.2 15.7 7.1

TABLE 15.5
(Continued)
<table>
<thead>
<tr>
<th>Reference</th>
<th>Food Item</th>
<th>Trans-Fatty Acids</th>
<th>% Fatty Acids</th>
<th>g/100 g Food</th>
<th>Min</th>
<th>Max</th>
<th>Avg ± SD</th>
<th>Min</th>
<th>Max</th>
<th>Avg ± SD</th>
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<tbody>
<tr>
<td>Michels and Sacks</td>
<td>(1995)</td>
<td>United Kingdom</td>
<td>margarine</td>
<td>“no trans”</td>
<td>margarine</td>
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<td>Boatella et al. (1993a)</td>
<td>Spanish</td>
<td>margarines</td>
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<td>(47)</td>
<td>10.8</td>
<td>± 8.8</td>
<td>8.02</td>
<td>14.11</td>
<td>3.93</td>
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<tr>
<td>Fernandez San Juan</td>
<td>(1996)</td>
<td>Spanish margarines</td>
<td>(32)</td>
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<td>± 5.7</td>
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<td>Larque et al. (2003)</td>
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<td>margarines</td>
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<td>(12)</td>
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<td>Bayard and Wolff</td>
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<td>French margarines</td>
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<td>trans (5)</td>
<td>0.06</td>
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<td>trans (7)</td>
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<td>Ovesen et al. (1996)</td>
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<td>1992, &lt;20%</td>
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<td>10.6</td>
<td>5.8</td>
<td>h</td>
<td>5.8</td>
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<td>1992, 20%–40%linoleic</td>
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<td>1.9</td>
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<td>4.2</td>
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<td>1.2</td>
<td>h</td>
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<td>0</td>
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<td>± 3.8</td>
<td>5.8</td>
<td>3.1</td>
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<td>20%–40% linoleic</td>
<td>(19)</td>
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<td>3.1</td>
<td>± 3.3</td>
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<td>&gt;40% linoleic</td>
<td>(38)</td>
<td>0</td>
<td>1.9</td>
<td>0.4</td>
<td>± 0.8</td>
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<td>Leth et al. (2003)</td>
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<td>1995, &lt;10%</td>
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<td>6.2</td>
<td>2.2</td>
<td>1995,</td>
<td>10%–20%</td>
<td>linoleic</td>
<td>4.6</td>
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<td>1995, 20%–40%linoleic</td>
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<td>4.6</td>
<td>2.7</td>
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<td>Heckers and Melcher</td>
<td>(1978)</td>
<td>German margarines</td>
<td>Regular, 1976</td>
<td>(58)</td>
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<td>30.3</td>
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<td>Regular, 1973/1974 (61)</td>
<td>0.1</td>
<td>34.7</td>
<td>8.1</td>
<td>Low-calorie, 1976</td>
<td>(9)</td>
<td>0.2</td>
<td>11.2</td>
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<td>Low-calorie, 1973/1974 (8)</td>
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<td>1.9</td>
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Undeclared composition (1) 23.5 Continued

TABLE 15.5

(Continued)

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<th>Reference Food Item a,b</th>
<th>Trans-Fatty Acids % Fatty Acids g/100 g Food</th>
<th>Min</th>
<th>Max</th>
<th>Avg ± SD</th>
<th>Min</th>
<th>Max</th>
<th>Avg ± SD</th>
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<tr>
<td>Hydrogenated vegetable oils (6)</td>
<td>6</td>
<td>23.4</td>
<td>9.3 ± 6.9</td>
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<td>Hydrogenated vegetable oils containing some animal fat (5)</td>
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<td>18.8</td>
<td>10.1 ± 5.9</td>
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<td>Diet and reduced fat margarines (4)</td>
<td>0.6</td>
<td>3.6</td>
<td>1.6 ± 1.4</td>
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<td>Reformatory</td>
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<td>Pfalzgraf and Steinhart (1995) German margarines</td>
<td>Margarine, vegetable oils (10)</td>
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<td>4.1 ± 1.9</td>
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<td>SunKower (4)</td>
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<td>16.1 ± 5.3</td>
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<td>Diet, reduced fat (4)</td>
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<td>2.3 ± 1.2</td>
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<td>Dietary/reformatory (6)</td>
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<td>1.3 ± 0.7</td>
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<td>h Diet/reformatory (31)</td>
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<td>Vegetable (5)</td>
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<td>0.53 SunKower (3)</td>
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<td>4.88</td>
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<td>Soft table</td>
<td>0.13</td>
<td>16.51 Soft table (lowest in trans) (10)</td>
<td>0.11</td>
<td>2.61 Soft table (highest in trans) (11)</td>
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<td>21.77 ± 3.3</td>
<td>1999 (9)</td>
<td>1.98</td>
<td>6.15</td>
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<td>5.37 ± 1.31</td>
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<td>1991/1992 tub (183)</td>
<td>15.72 ± 5.84</td>
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<td>1991/1992 dietary (124)</td>
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<td>1995 stick (14)</td>
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<td>1995 tub (28)</td>
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<td>1995 dietary (40)</td>
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<td>Reference Food Item a,b Trans-Fatty Acids % Fatty Acids</td>
<td>g/100 g Food</td>
<td>Min</td>
<td>Max</td>
<td>Avg</td>
<td>± SD</td>
<td>Min</td>
<td>Max</td>
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</tr>
<tr>
<td>Hard household (lowest in trans) (7)</td>
<td>0.09</td>
<td>14.29</td>
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<tr>
<td>Hard household (highest in trans) (8)</td>
<td>6.27</td>
<td>28.07</td>
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<td>Low-fat spreads (typical) (12)</td>
<td>0.16</td>
<td>13.29</td>
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<tr>
<td>Low-fat spreads (lowest in trans) (10)</td>
<td>0.13</td>
<td>12.27</td>
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<tr>
<td>Low-fat spreads (highest in trans) (9)</td>
<td>1.10</td>
<td>15.99</td>
<td></td>
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</tr>
</tbody>
</table>

Marekov et al. (2002) Bulgarian margarine k <0.2 11.2
Triantaflou et al. (2002) Greek margarine (15) 0.1 19.0
Demirbas and Yilmaz (2000) Turkish margarine Hard 15.95 Soft 5.55 Breakfast 6.74 Paste and cake 18.32
Araci et al. (2002) Turkish margarine k Hard (8) 20.1 34.3 Soft (8) 0.8 8.9
Tekin et al. (2002) Turkish margarine k Tub (1) 7.7 Stick (7) 18.0 37.8
Cetin et al. (2003) Turkish margarine (10) h,k 0.2 27.4
Enig et al. (1984) Israeli margarines Hard (3) 30.8 34.2 32.8 Soft (2) 13.4 14.3 13.9
Bhanger and Anwar (2004) Pakistan margarines (11) 1.45 23.09
Khaloui et al. (1998) Marocan margarines 33.7 ± 2.5
Parodi (1976a) Australian margarines PUFA margarines (40) 12.9 22.1 17.1 Margarine (7) 10.8 19.0 14.9
Wills et al. (1982) Australian margarines (12) 4 14 11.0 ± 2.5
Mansour and Sinclair
the trans,trans-isomer in amounts exceeding 1% of the fatty acids. Linoleate (18:2Δ9c, 12c) was found in much greater amounts, ranging from 6.1% to 46.4%. Whether the small amounts of trans, trans-diene found in margarine would interfere with essential fatty acid and prostaglandin metabolism, particularly if the overall diet provided adequate sources of linoleic acid, is not known. Depending on the starting material, additional trans-isomers may be formed in margarine.

For example, if marine oils are hydrogenated, trans-isomers of C20 and C22 fatty acids are present in the final product (Ovesen et al., 1996). Similarly, if the original oil contains significant quantities of 18:3n-3, trans-isomers of 18:3 are formed (Ratnayake et al., 1991; Ratnayake and Pelletier, 1992).

G. SHORTENINGS

Values reported for shortenings made from hydrogenated vegetable oils range from 6% to 50% trans-fatty acids (Table 15.7). Scholfield et al. (1967) reported that the average trans-fatty acid content of four vegetable shortenings was 22.5%. This value agrees with the value of 26% trans-fatty acids used by Hunter and Applewhite (1986) to estimate trans-fatty acid intake from shortenings in 1960. According to values of the Institute of Shortening and Edible Oils (ISEO), the typical trans fatty acid content of household vegetable shortenings decreased from 26% in 1960 to 17% in 1984.
(Hunter and Applewhite, 1986). Enig et al. (1983) analyzed seven brands of shortening, including household brands as well as commercial frying fats (Table 15.7). The trans-isomer content (18:1t plus 18:2i) of these shortenings averaged 25.3% of total fatty acids, with values for the trans-isomers of octadecadienoic acid (18:2i) ranging from 1.9% to 4.4%. The average value reported by Smith et al. (1986) for trans-fatty acid content of commercial frying fats collected in California was 41.5% of total fatty acids. The content of trans-fatty acids in these shortenings was reported to decrease during

**TABLE 15.5**

(Continued)

<table>
<thead>
<tr>
<th>Reference Food Item a,b</th>
<th>Trans-Fatty Acids % Fatty Acids g/100 g Food</th>
<th>Min</th>
<th>Max</th>
<th>Avg ± SD</th>
<th>Min</th>
<th>Max</th>
<th>Avg ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake et al. (1996) New Zealand margarines Margarine (7)</td>
<td>12.6 19.7 16.4 ± 2.60 Table spreads (5)</td>
<td>14.3 16.9 15.7 ± 1.07 Butter/margarine blend (2)</td>
<td>6.1 13.1 9.6 ± 4.96</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Richardson et al. (1997) New Zealand margarine (2) 14.3 14.66 14.50 ± 0.23

- a Number in parentheses following food item indicates number of samples/brands analyzed.
- b PUFA = polyunsaturated fatty acids.
- c Average includes one sample containing tropical oils; average if this sample is omitted = 30.8%.
- d Based on margarine consumption of 20% tub and 80% stick.
- e Data expressed as percentage of corresponding triglyceride.
- f Margarines containing various combinations of vegetable oils, animal fat, and marine oil.
g Weighted mean.

h Represents only trans-18:1 content.

i Personal communication (1986) from Martin Leigh eld, Nuffield Laboratories of Comparative Medicine, Institute of Zoology, Regent’s Park, London.

j Number of European countries from which samples were analyzed appears in parentheses following food item. Values presented as range.

k Data expressed as percentage of methyl esters. Table 15.6 Trans Octadecenoate and Isomer of Octadecadienoate in Margarine Isomer of Octadecadienoate (% of Total Fatty Acids) 18:1 t 18:2 t, c 18:2 c, t 18:2 t, t 18:2 i 18:2 c, c. Enig et al. (1983) Margarine, U. S. Stick (24) 22.3 (15.9 - 31.0) --- 1.9 (0 - 5.2) 26.1 (8.2 - 46.5) Tu b (13) 12.7 (6.8 - 17.6) --- 1.7 (0 - 4.2) 34.6 (8.6 - 48.4) Diet (3) 2.0 (11.3 - 13.3) --- 3.3 (1.4 - 5.0) 3.6 (29.8 - 37.8) Slover et al. (1985) d Margarine, U. S. Stick (57) 22.23 (14.82 - 30.06) 0.61 (0 - 3.49) 0.69 (0.17 - 3.76) 0.16 (0 - 1.28) 1.46 (0.17 - 3.15) 0.25 (6.06 - 43.57) Tu b (26) 14.77 (10.74 - 18.44) 1.31 (0.10 - 4.78) 1.34 (0.19 - 5.31) 0.26 (0 - 1.47) 2.91 (0.35 - 11.56) 31.18 (19.46 - 46.39) Overall (83) 19.89 (10.74 - 30.06) 0.83 (0 - 4.78) 0.89 (0.17 - 5.31) 0.19 (0 - 1.47) 1.92 (0.35 - 11.56) 27.14 (6.06 - 46.39) Ratnayake et al. (1991) Margarine, Canadian Stick, soybean oil (3) 31.13 (23.8 - 40.8) 0.27 e (5.0 - 7.6) 1.23 (0.3 - 2.8) 0.3 (2.3 - 14.6) Stick, vegetable oil (5) 30.16 (23.6 - 30.2) 2.4 e (2.1 - 3.1) 0.5 (0 - 1.2) 8.06 (4.1 - 11.4) Stick, palm oil (7) 32.90 (30.4 - 40.6) 2.33 e (1.2 - 3.2) 0.44 (0.2 - 0.8) 4.6 (3.6 - 5.6) Stick, corn oil (1) 26.41.7 e 0.23 Stick, vegetable/animal fat (1) 37.23.1 e 1.44.8 Stick, unspeci (2) 0.6 (17.8 - 23.4) 3.4 e (2.0 - 4
<table>
<thead>
<tr>
<th>Fat Source</th>
<th>Trans Fat (% of Total Fat)</th>
<th>Isomer 18:1 t%</th>
<th>Isomer 18:2 t%</th>
<th>Isomer 18:2 c%</th>
<th>Isomer 18:2 t%</th>
<th>Isomer 18:2 i%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean oil (13)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
</tr>
<tr>
<td>Vegetable oil (10)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
</tr>
<tr>
<td>Palm oil (2)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
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<tr>
<td>Corn oil (3)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
</tr>
<tr>
<td>Sunflower oil (2)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
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<tr>
<td>Olive oil (1)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
<td>0.20 (0.0 - 0.4)</td>
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Continued

6. Continued Reference Margarine

<table>
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<tr>
<th>Fat Source</th>
<th>Trans Fat (% of Total Fat)</th>
<th>Isomer 18:1 t%</th>
<th>Isomer 18:2 t%</th>
<th>Isomer 18:2 c%</th>
<th>Isomer 18:2 t%</th>
<th>Isomer 18:2 i%</th>
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</thead>
<tbody>
<tr>
<td>Butter/margarine blends</td>
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(Continued)
2 4 . 4 ( 2 1 . 7 – 2 7 . 1 ) F r i t s c h e a n d S t e i n h a r t ( 1 9 9 7 ) G e r m a n m a r g a r i n e s F a t r e d u c e d ( 2 ) ( 0 . 6 8 – 1 . 5 5 ) ( 0 . 1 2 – 0 . 1 7 ) ( 0 . 0 – 0 . 0 ) V e g e t a b l e ( 5 ) ( 0 . 1 9 – 3 . 8 3 ) ( 0 . 1 0 – 0 . 1 3 ) ( 0 . 0 – 0 . 1 3 ) D i e t ( 7 ) ( 0 . 0 5 – 0 . 3 6 ) ( 0 . 0 – 0 . 4 3 ) ( 0 . 0 – 0 . 0 3 ) S a n K o w e r ( 3 ) ( 2 . 9 7 – 4 . 3 5 ) ( 0 . 1 8 – 0 . 3 3 ) ( 0 . 0 – 0 . 1 9 ) L a r q u e et a l . ( 2 0 0 3 ) S p a n i s h m a r g a r i n e s ( 1 2 ) 4 . 6 ± 6 . 5 ( 0 . 1 – 1 0 . 6 ) 0 . 1 ± 0 . 0 ( 0 . 1 – 0 . 2 ) 0 . 1 ± 0 . 0 ( 0 . 1 – 0 . 2 ) C e t i n et a l . ( 2 0 0 3 ) T u r k i s h m a r g a r i n e ( 1 0 ) ( 0 . 2 – 2 7 . 4 ) ( 0 . 3 – 1 3 . 7 ) e M o n g e R o j a s et a l . ( 2 0 0 5 ) C o s t a R i c a n m a r g a r i n e s 6 . 8 0 . 5 f a N u m b e r s i n p a r e n t h e s e s i n d i c a t e n u m b e r o f s a m p l e s a n a l y z e d . b S u m o f 1 8 : 2 t , c + 1 8 : 2 c , t + 1 8 : 2 t , t = 1 8 : 2 i . c 1 8 : 2 c , c = a l l c i s l i n o l e i c a c i d . d D a t a f r o m S l o v e r , H . T . , e t a l . ( 1 9 8 5 ) . J . A m . O i l C h e m . S o c . 6 2 : 7 7 5 – 7 8 6 . R e p o r t ed a s i s o m e r s o f ∆ 9 , 1 2 o c t a d e c a d i e n o a t e s ( n o r m a l i z e d w t . % , a s t r i g l y c e r i d e s ) . e I n c l u d e s b o t h 1 8 : 2 t , c a n d 1 8 : 2 c , t . f I n c l u d e s b o t h 1 8 : 2 c , t a n d 1 8 : 2 t , t ; d a t a e x p r e s s e d a s g / 1 0 0 g f o o d . T A B L E 1 5 . 7 T r a n s F a t t y A c i d C o n t e n t o f S h o r t e n i n g s a R e f e r e n c e F o o d I t e m b T r a n s F a t t y A c i d s ( % ) c g / 1 0 0 g F o o d M i n M a x M a x A v g d S c h o l e l d e t a l . ( 1 9 6 7 ) U . S . v e g e t a b l e s h o r t e n i n g s ( 4 ) 1 6 . 6 2 9 . 2 2 2 . 5 e S l o v e r a n d L a n z a ( 1 9 7 9 ) U . S . v e g e t a b l e vegetable horten ( 1 ) 1 0 . 7 L a n z a a n d S l o v e r ( 1 9 8 1 ) U . S . s h o r t e n i n g s V e g e t a b l e Oil s o n l y ( 6 ) 8 . 0 2 3 . 9 1 4 . 5 M e a t f a t s + v e g e t a b l e o i l s ( 3 ) 2 . 8 6 . 6 4 . 3 E n i g et a l . ( 1 9 8 3 ) U . S . v e g e t a b l e s h o r t e n i n g s ( 7 ) 1 3 . 0 3 7 . 3 2 5 . 3 S m i t h et a l . ( 1 9 8 6 ) U . S . c o m m e r c i a l b r a n d s f F r e sh ( 9 ) 4 0 . 4 4 2 . 4 4 1 . 5 U s e d ( 5 6 ) 1 2 . 8 4 1 . 4 3 0 . 7 H u n t e r a n d A p p l e w h i t e ( 1 9 8 1 ) U . S . sh o r t e n i n g s V e g e t a b l e , 1 9 7 0 2 6 V e g e t a b l e , 1 9 7 0 1 9 V e g e t a b l e , 1 9 8 4 1 7 A n i m a l f a t s , 1 9 6 0 – 1 9 8 4 1 0 Pfl a 1 7 g r a f et al . ( 1 9 9 3 ) G e r m a n f r y i n g a n d b a k i n g f a t s ( 5 ) 0 . 1 3 1 . 8 1 2 . 7 2 ± 0 . 1 4 L i t i n a n d S a c k s ( 1 9 9 3 ) U . S . v e g e t a b l e s h o r t e n i n g s 1 3 . 4 R a t n a y a k e et a l . ( 1 9 9 3 ) C a n a d i a n sh o r t e n i n g s.
<table>
<thead>
<tr>
<th>Food Item</th>
<th>Trans Fatty Acids (%)</th>
<th>g/100g</th>
<th>Min</th>
<th>Max</th>
<th>Avgd</th>
<th>Min</th>
<th>Max</th>
<th>Avgd</th>
<th>Molex</th>
<th>1991, 1992 (86)</th>
<th>1995 (15)</th>
<th>1996 (16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unhydrogenated fats (3)</td>
<td>2.0 ± 0.6</td>
<td>17.2</td>
<td>11.4</td>
<td>10.0</td>
<td>9.6</td>
<td>15.8</td>
<td>14.5</td>
<td>14.2</td>
<td>6.8</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
<td></td>
</tr>
<tr>
<td>Hydrogenated fats (3)</td>
<td>2.2 ± 0.3</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
<td></td>
</tr>
<tr>
<td>Bayard and Wolff (1995)</td>
<td>2.0 ± 0.2</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
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</tr>
<tr>
<td>French shortenings (3)</td>
<td>2.0 ± 0.5</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
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<tr>
<td>Danish shortenings / frying oils</td>
<td>17.4 ± 2.0</td>
<td>19.6</td>
<td>15.9</td>
<td>13.2</td>
<td>12.8</td>
<td>17.9</td>
<td>16.2</td>
<td>16.0</td>
<td>10.8</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
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<tr>
<td>Hardened, new #1</td>
<td>17.4 ± 2.0</td>
<td>19.6</td>
<td>15.9</td>
<td>13.2</td>
<td>12.8</td>
<td>17.9</td>
<td>16.2</td>
<td>16.0</td>
<td>10.8</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
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<tr>
<td>Nonhardened, new #0</td>
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<td>15.9</td>
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<tr>
<td>USDA (1995)</td>
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<td>15.9</td>
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<td>U.S. shortenings (12)</td>
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<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
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<tr>
<td>Cham and Precht (1995, 1996)</td>
<td>0.0 ± 0.1</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
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<tr>
<td>Germans shortenings / cooking fats (16)</td>
<td>0.0 ± 0.1</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
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<tr>
<td>Austrians shortenings 1991/1992</td>
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<td>11.7</td>
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<td>15.9</td>
<td>14.6</td>
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<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
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<tr>
<td>Henninge and Ulberth (1996)</td>
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<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
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<tr>
<td>New Zealand shortenings (3)</td>
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<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
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<tr>
<td>Danish shortenings 1995, &lt;10% linoleic (17)</td>
<td>5.4 ± 2.0</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
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<tr>
<td>Danish shortenings 1999, 10%–20% linoleic (36)</td>
<td>6.5 ± 3.3</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
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<tr>
<td>New Zealand shortenings (11)</td>
<td>5.4 ± 2.0</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
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<tr>
<td>Nigerian shortenings (10)</td>
<td>5.4 ± 2.0</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
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<td>1995 (15)</td>
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<tr>
<td>Danish shortenings 1995 (17)</td>
<td>5.4 ± 2.0</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
<td></td>
</tr>
<tr>
<td>Danish shortenings 1999 (10)</td>
<td>5.4 ± 2.0</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
<td></td>
</tr>
<tr>
<td>Danish shortenings 1999, 10%–20% linoleic (24)</td>
<td>5.5 ± 4.5</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
<td></td>
</tr>
<tr>
<td>Pakistani shortenings (11)</td>
<td>7.3 ± 4.6</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
<td></td>
</tr>
<tr>
<td>Total shortenings (4)</td>
<td>12.6 ± 3.2</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
<td></td>
</tr>
<tr>
<td>Costa Rican shortenings, palm 0.55 (14)</td>
<td>7.3 ± 4.6</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
<td></td>
</tr>
<tr>
<td>Monge Rojas et al. (2005)</td>
<td>5.4 ± 2.0</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
<td></td>
</tr>
<tr>
<td>Costa Rican shortenings, 9% fat content of shortening = 100%</td>
<td>5.4 ± 2.0</td>
<td>17.4</td>
<td>11.7</td>
<td>10.2</td>
<td>9.8</td>
<td>15.9</td>
<td>14.6</td>
<td>14.2</td>
<td>6.9</td>
<td>1995 (15)</td>
<td>1996 (16)</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**
- Number of samples analyzed appear in parentheses following food item.
- Percentage of total fatty acids.
- Mean ± SD.
- Determined by IR methods.
- Frying fats collected from nine restaurants in California.
- Data
On typical trans fatty acid levels of products obtained from member companies of the Institute of Shortening and Edible Oils (ISEO). Total represents only trans 18:1 content.

Commercial deep-fat frying in fast food restaurants. The trans-C 18 monoenes in these commercial fats decreased from over 40% in the fresh fat to as low as 13% in the used product (Table 15.7). German and Austrian shortenings (Pfalzgraf et al., 1993; Molkentin and Precht, 1995, 1996; Henninger and Ulberth, 1996) appear to be somewhat less in trans-fatty acid content compared with those sold in North America. On the other hand, French shortenings were reported by Bayard and Wolff (1995) to contain relatively large amounts of trans-fatty acids (28%-64%, with an average of 50%). Ovesen and Leth (1955) reported that Danish shortenings made from hydrogenated fat contained 30%-37% of total fatty acids as trans-isomers; however, more recently Ovesen et al. (1996) reported 7% for Danish shortenings. New Zealand shortenings appear to be relatively low in trans fatty acids, with an average value of approximately 6% (Richardson et al., 1997). Like margarines, shortenings are also being reformulated to contain less trans-fat. Precht and Molkentin (2000) reported that the trans-content of German shortenings decreased from 12% of total fatty acids in 1994 to 6% in 1999. There is movement worldwide to make shortenings with little or no trans-fatty acids available to the baked goods industry.

H. VEGETABLE OILS

In general, nonhydrogenated vegetable oils contain minimal trans-fatty acids (Table 15.8). However,
in the past soybean oil sold for use as salad and cooking oil was often lightly hydrogenated to reduce the content of α-linolenic acid (18:3) and thereby reduce the potential for oxidation and rancidity.

**TABLE 15.8**

Trans-Fatty Acid Content of Vegetable Oils

<table>
<thead>
<tr>
<th>Reference Food Item a</th>
<th>Trans-Fatty Acids (%) b</th>
<th>Min</th>
<th>Max</th>
<th>Avg c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schold et al. (1967) Vegetable oils (2)</td>
<td>4.9</td>
<td>12.0</td>
<td>8.5</td>
<td>d</td>
</tr>
<tr>
<td>Carpenter et al. (1976) Vegetable oils “Specially processed” (5)</td>
<td>5.6</td>
<td>13.3</td>
<td>9.7</td>
<td>Other (9) 0</td>
</tr>
<tr>
<td>Enig et al. (1983) Soybean oil, partially Hydrogenated (4)</td>
<td>11.0</td>
<td>13.4</td>
<td>12.4</td>
<td>Other vegetable oils e (14) tr</td>
</tr>
<tr>
<td>Ball et al. (1993) New Zealand vegetable oils Rapeseed 0.9 SafK ower 0.4 Soya 0.6 Corn 1.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boatella et al. (1993a) Spanish vegetable oils Reï ned olive oil (12) 0.5 ± 0.2 Seeds oils (12) 2.3 ± 0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Litin and Sacks (1993) U.S. vegetable oil 0 1.06 0.42 g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pfalzgraf et al. (1993) German vegetable oils 0 Plant oils (6) 1.5 0.20 ± 0.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Almond oil (1) 0.1 Continued</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 15.8 (Continued)**

<table>
<thead>
<tr>
<th>Reference Food Item a</th>
<th>Trans-Fatty Acids (%) b</th>
<th>Min</th>
<th>Max</th>
<th>Avg c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peanut oil (1) 0.5</td>
<td>Walnut oil (1) 0.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USDA (1995) U.S. vegetable oils Canola oil (2) 0.17 0.23 0.20 ± 0.04 SunK ower oil (1) 0.5 Olive oil (1) 0.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fernandez San Juan (1996) Spanish vegetable oil Olive (30) 0.1 ± 0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Aro et al. (1998b) European vegetable oils

<table>
<thead>
<tr>
<th>Food Item</th>
<th>0</th>
<th>0.11</th>
<th>0.4</th>
<th>0.86</th>
<th>Sunflower oil</th>
<th>0.13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olive oil (4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean oil (3)</td>
<td>0.89</td>
<td>0.11</td>
<td>1.91</td>
<td>Rapeseed oil (1)</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>Peanut oil (2)</td>
<td>0.04</td>
<td>0.63</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bhanger and Anwar (2004) Pakistani hydrogenated vegetable oils (vegetable ghee)

<table>
<thead>
<tr>
<th>Palmitic</th>
<th>Stearic</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;40%</td>
<td>&lt;8.5%</td>
</tr>
<tr>
<td>&lt;40%</td>
<td>&lt;8.5%</td>
</tr>
<tr>
<td>&gt;8.5%</td>
<td></td>
</tr>
</tbody>
</table>

Satchithanandam et al. (2004) U.S. vegetable oils

<table>
<thead>
<tr>
<th>Food Item</th>
<th>0</th>
<th>0.1</th>
<th>0.3</th>
<th>Saf K oil (2)</th>
<th>0.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canola oil (4)</td>
<td></td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean oil (4)</td>
<td>0.1</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olive oil (2)</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virgin olive oil (2)</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extra virgin olive oil (2)</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spanish olive oil (2)</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn oil (2)</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ratnayake and Zehaluk (2005) Canadian refined oils

<table>
<thead>
<tr>
<th>Food Item</th>
<th>2.42</th>
<th>1.89</th>
<th>0.47</th>
<th>0.74</th>
<th>0.73</th>
<th>1.06</th>
<th>0.19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canola oil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean oil</td>
<td>1.89</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn oil</td>
<td>0.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunflower oil</td>
<td>0.74</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rapeseed oil</td>
<td>0.73</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice bran</td>
<td>1.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coconut</td>
<td>0.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extra virgin olive oil</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a Number of samples analyzed appears in parentheses following food item.
b Percentage of total fatty acids; tr = trace.
c Mean ± SD.
d Determined by IR methods.
e Includes cottonseed oil (2), soybean oil (2), corn oil (3), peanut oil (1), olive oil (1), saf K oil (1), sunflower oil (1), vegetable oils (mixture or unspeci ed (3)). Trace amounts of trans-fatty acids were detected in two samples.
f Data on typical trans-fatty acid levels of products obtained from member companies of the Institute of Shortening and Edible oils (ISEO).
h Number of European countries from which samples were analyzed appears in parentheses following food item. Data expressed as percentage of fatty acid methyl esters.
Reported values for the trans-fatty acid content of hydrogenated salad and cooking oils range from 5% to 15% (Table 15.8), with average values in the 1980s ranging from 8% (ISEO data; Hunter and Applewhite, 1986) to 12% (Enig et al., 1983). One exception to this is the trans-fatty acid content of Pakistani-hydrogenated vegetable oils (vegetable ghee/vanaspati) reported by Bhanger and Anwar (2004). These values for the trans-fatty acid content of ghee range from 14% to 34% of total fatty acids and are much greater than those reported for vegetable oils in other countries. The content of trans-18:2 dienes (18:2\text{t}) in hydrogenated vegetable oils is high in comparison to the trans-18:1 content. For example, in one sample of partially hydrogenated soybean oil analyzed by Enig et al. (1983), 18:2\text{t} was 5.6% of the total fatty acids, with 18:1\text{t} comprising only 7.0%.

Linoleate (18:2\text{c,c}) was reported to be 36.2% in this product. Thus, lightly hydrogenated products appear to have proportionately more trans-dienes and fewer trans-monoenes than more heavily hydrogenated products. Many brands of salad and cooking oils contain oils that are not hydrogenated and thus contain no or only small amounts of trans-isomers (Table 15.8). Hunter (1990) has reported that since the mid-1980s, manufacturers have increased their production of household salad and cooking oils made from unhydrogenated oils. Processing of these oils can result in a minimal level of trans-fatty acids (Table 15.8). For example, Innis et al. (1999) reported that the content of nonhydrogenated vegetable oils ranged from 0.05 g/100 g food for extra virgin oil to
2.42 g/100 g of food for canola oil. Thus, these products contribute very little trans-fatty acids to the current food supply in the United States, Canada, or other countries.

I. SALAD DRESSINGS, MAYONNAISE, SOUPS, AND SAUCES

Several samples of salad dressings, mayonnaise, and other sauces were analyzed for trans-fatty acids by a number of investigators (Table 15.9). This category of food contributes only small amounts of trans-fatty acids to the diet, and many of the products analyzed contain no trans-fatty acids (Table 15.9). For example, two out of the three salad dressings analyzed by Slover et al. (1980) contained small amounts of trans-fatty acids (0.24%), but none of the seven brands tested by Enig et al. (1983) contained trans-fatty acids. Of the five brands of mayonnaise analyzed by Slover et al. (1980) and Enig et al. (1983), only two contained trans-fatty acids. Elias et al. (2002) reported that most salad dressings contained less than 2 g/100 g of food as trans-fatty acids. Satchithanandam et al. (2004) found similar values for mayonnaise and salad dressings. Prepared soups contain significant amounts of trans-fatty acids with values ranging from 10% for beef bouillon to 35% for onion cream soup (Pfalzgraf et al., 1993; USDA, 1995; Fernandez San Juan, 1996; Aro et al., 1998c; Innis et al., 1999). Thus, soups can contribute reasonably large amounts of trans-fatty acids to the diet if they are consumed routinely.

J. TRANS-ISOMERS OF FATTY ACIDS IN FAST FOODS AND PROCESSED FOODS
Because commercial shortenings containing relatively large amounts of trans-fatty acids (Smith et al., 1986) are used as frying fats in fast food establishments and other restaurants, fast foods have the potential to contain relatively large amounts of trans-fatty acids. In addition, hydrogenated fats are used in many processed foods because of the increased shelf life, as well as the dependable consistency, the hydrogenation process affords the products. Therefore, many processed foods including cookies and other baked goods would be expected to contain significant amounts of trans-isomers. In fact, several investigators including Elias and Innis (2002) in Canada and Lemaitre et al. (1998) in the United States report that the greatest source of trans-fatty acids in the North American diet is baked goods. Values for the trans-fatty acid content of processed foods and fast foods vary widely, depending on the type of fat used in processing. For this reason, some investigators prefer to present their data as ranges rather than as means. Values for the trans-fatty acid content of fast food items and processed foods are summarized in the remainder of this section.

### TABLE 15.9

Trans-Fatty Acid Content of Salad Dressings, Mayonnaise, Soups, and Sauces

<table>
<thead>
<tr>
<th>Reference Food Item a</th>
<th>Trans-Fatty Acids (%) b</th>
<th>(g/100 g Food)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slover et al. (1980) U.S. salad dressings (2)</td>
<td>0.24</td>
<td>U.S. salad dressings (1) n.d.</td>
</tr>
<tr>
<td>Slover et al. (1980) U.S. mayonnaise (1)</td>
<td>0.34</td>
<td>U.S. tarter sauce (1) 0.37</td>
</tr>
<tr>
<td>Slover et al. (1980) U.S. burger sauce (2)</td>
<td>0.14</td>
<td></td>
</tr>
</tbody>
</table>

| U.S. mayonnaise (3) n.d. U.S. burger sauce (1) 4.6 |
Litin and Sacks (1993) U.S. mayonnaise, reduced calorie 0.21

Pfalzgraf et al. (1993) c German soups Clear soup 28.3
Beef bouillon 9.9 Onion cream soup 34.9 German sauces
Curry sauce 25.4 Instant tomato sauce 2.9 Mayonnaise 0.4

USDA (1995) U.S. salad dressings French (2) 0.64 ± 0.11
0.24 ± 0.04 Italian (2) 0.94 ± 0.64 0.40 ± 0.21 Low
calorie (1) 0.91 0.19 Ranch (1) 8.95 3.71 Low calorie
(2) 13.17 ± 0.89 1.57 ± 1.79 U.S. mayonnaise (2) 2.38 ±
2.94 1.82 ± 2.24 U.S. soups Beef bouillon cubes (3) 19.54
± 13.75 1.25 ± 1.69 Chicken bouillon cubes (3) 20.33 ±
20.49 1.41 ± 2.12

Ali et al. (1996) U.S. salad dressing, blue cheese (1) 5.47
1.21

Fernandez San Juan (1996) c Spanish soups, dehydrated (42)
15.4 ± 9.4

Aro et al. (1998c) c European soups (4) 6.57–30.13 European
sauces (6) 0.20–38.63

Innis et al. (1999) Canadian soups (11) 22.4 (1.1–51.6) 2.6
(0–9.1)

Elias et al. (2002) Canadian salad dressing, oil/vinegar
(8) 1.4 ± 0.3 1.4 ± 0.3 Canadian salad dressing, creamy
(10) 1.3 ± 0.4 1.3 ± 0.4

Satchithanandam et al. (2004) U.S. mayonnaise (6) 0.2–0.5
U.S. light mayonnaise (2) 0.0 U.S. salad dressings Ranch
(4) 0.1 Creamy ranch (2) 0.6 Fat-free ranch (2) 0.0
Italian dressing (8) 0.2–2.2 Olive oil and vinegar (2) 0.2
Reduced-fat dressing (2) 0.0

a Number of samples analyzed appears in parentheses
following food item.

b Percentage of total fatty acids; n.d. = not detected.

c Number of European countries from which samples were
analyzed appears in parentheses following food item. Values
presented as range. Data expressed as percentage of fatty
acid methyl esters.

K. FAST FOODS

Fast food items can be a significant source of trans-fatty
acids in the diet. In the lunch/dinner items
analyzed (Table 15.10), the trans-fatty acid content varied from 0.04 g/100 g food for milk shakes to
1.38 g/100 g food for fried pies and turnovers to 3.0 g/100 g of food for French fries. Hamburgers,
as well as items such as fried fish and fried chicken, are all sources of trans-fatty acids. Based on the
data of Lanza and Slover (1981), a typical fast food meal could provide 3-4 g of trans-fatty acids
(Table 15.11), and even more if the USDA (1995) data for French fries are used. Recently, Stender et al. (2006)
reported that a fast food meal of French fries and chicken
nuggets contained over 10 g of industrially produced trans-fatty acids if purchased at McDonald’s
in New York City, USA, or almost 25 g if purchased at Kentucky Fried Chicken in Hungary.
Breakfast items would also provide trans-fatty acids, with pastries providing relatively high amounts
(Table 15.10). The values for trans-fatty acids in fast foods, however, must be interpreted with caution, because
many fast food restaurants have changed the type of fat used for frying since the analyses were done
by Slover et al. (1980). On the other hand, if the data of Smith et al. (1986) on commercial frying
fats and that of Pfaltzgraf et al. (1993), Fernandez San Juan (1996), USDA (1995) are typical of
products used in the 1980s and 1990s, then fast food items in the United States and some countries
in Europe contained significant amounts of trans-isomers at that time. In other countries, such as
New Zealand (Lake et al., 1996), the trans-fatty acid content of commercial frying fats used in fast
food restaurants appears to be less than in the United States; thus, the trans-content of a fast food
meal in these countries would be expected to be less. The report by Stender et al. (2006) on the trans-fatty acid content of chicken nuggets and French fries purchased at McDonald’s or Kentucky Fried Chicken gives an interesting cross-country comparison. For a fast food meal at McDonald’s, 5–10 g of industrially produced trans-fatty acids would be obtained if the meal was purchased in the United States, Peru, United Kingdom, South Africa, Poland, Finland, France, Italy, Norway, Spain, Sweden, Germany, or Hungary. The same meal of chicken nuggets and French fries would contain 1–5 g of trans-fat only if it were purchased in Austria, Portugal, the Netherlands, Russia, Czech Republic, or Spain. Only if the meal were purchased in Denmark would contain less than 1 g of trans-fatty acids. A meal of French fries and chicken from Kentucky Fried Chicken would contain 10–25 g of trans-fatty acids if purchased in Hungary, Poland, Peru, or Czech Republic; 5–10 g in the Bahamas, South Africa, or USA; 2–5 g in Germany (Hamburg), France, United Kingdom (London or Glasgow), Spain, or Portugal; and less than 2 g in United Kingdom (Aberdeen), Denmark, Russia, or Germany (Wiesbaden). Thus, the trans-fatty acid content of fast food can vary widely depending on the country and even the city.

L. PROCESSED FOODS

Several investigators have reported values for the trans-fatty acid content of snack items (Table 15.12). The trans-isomer content of these food items is highly variable, with some brands providing negligible amounts and others containing as much as 30%-50% of the
fatty acids as trans-isomers. Enig et al.
(1990b) contend that the trans-content of many of these snack items increased when food analyzed in 1978 were compared with comparable items analyzed a decade later. However, when labeling laws were implemented in 2006 in the United States, many snack items were reformulated and advertised as containing “0 trans.” The most comprehensive early analysis of processed food items is that published by Enig et al. (1983). In this study, the fat in 220 samples from 35 food types was analyzed for individual fatty acids including trans-octadecenoic acid (Table 15.13). None of the samples of peanut butter contained trans-fatty acids. Maximum values in the other categories ranged from 24% to 39% of the fatty acids as trans-isomers. Mean values for the trans-content of samples in which any amount of trans-fatty acids was detected ranged from 11% to 28%.

<table>
<thead>
<tr>
<th>Table 15.10 Trans-Fatty Acid Content of Fast Foods Reference Food Items</th>
<th>trans-Fatty Acid Content Fat Content (wt. %)</th>
<th>% of Fatty Acids</th>
<th>g/100g Food</th>
<th>Min</th>
<th>Max</th>
<th>Avg</th>
<th>Min</th>
<th>Max</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lunch/dinner items Slover et al. (1980)</td>
<td>Hamburgers (10)</td>
<td>3.00</td>
<td>5.16</td>
<td>3.73</td>
<td>Lanza and Slover (1981)</td>
<td>Hamburger (10)</td>
<td>0.38</td>
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</table>
Hydrogenated fat (1) 0.6 6.35.5 Slover et al. (1980) Ham/cheeses sandwiches (1) 1.6 2.6 Lanza and Slover (1981) Ham/cheeses sandwiches (1) 0.1 1.3 Slover et al. (1980) Fish sandwiches (4) 1.393.5 0.75 Lanza and Slover (1981) Fish sandwiches (4) 0.2 20.4 30.3 15.4 Smith et al. (1985) Fried sandwich pieces (4) 5.8 29.9 0.1 Enig et al. (1983) Fried sandwich (3) 0 1.5 2.2 Enig et al. (1990a) Fried sandwich (4) 2 2.9 33.5 Mozaffarian et al. (2006) Breaded sh burger (3) 0.8 8.6 Slover et al. (1980) Fish platter (1) 4.5 9.9 Lanza and Slover (1981) Fish platter (1) 0.7 61 8.6 Slover et al. (1980) Beef platter (1) 3.5 4.4 Lanza and Slover (1981) Beef platter (1) 0.6 92 0.4 Smith et al. (1985) Fried chicken pieces, thigh (5) 7.7 16.4 13.8
.8 Elias et al. (2002) Chicken nuggets (3) 29.5 56.7 42.3 ± 13.0 Huang et al. (2006) e, f Chicken nuggets 2.08 ± 0.53 3.32 ± 0.6 Huang et al. (2006) e, f Chicken strips 4.86 ± 0.8 Stenderetal. (2006) Chicken nuggets (24) McDonald’s 114 Chicken nuggets (19) Kentucky Fried Chicken 0.438 Mozaffarian et al. (2006) Breaded chicken nuggets 25 Elias et al. (2002) Potato nuggets (2) 44.5 46.3 45.4 Slover et al. (1980) French fries (3) 3.874.1 34.02 Lanza and Slover (1981) French fries (3) 0.520.7 20.60.1 1 Enigetal. (1983) g French fries (3) 4.65 14.8 French fries (4) 6.237.4 17.8 Smith et al. (1985) French fries (6) 6.334.1 13.5 Enigetal. (1990a) French fries (4) 3.2 25.8 Litin and Sacks (1993) French fries (2) 2.123.0 22.6 Pfalzgrafetal. (1993) b French fries (2) 22.5 32.8 27.7 Ratnayake et al. (1993) d French fries (1) n. d. 17.2 USDA (1995) French fries (7) 7.33 4.220.6 1.05 23.0 16.0 Fernandez San Juan (1996) b French fries (15) 20.9 20.4 Lake et al. (1996) i French fries (2) 5.45 0.56 64 6.937.75 8 Elias et al. (2002) French fries (15) 4.9 56.939.6 415.3 Huang et al. (2006) e, f French fries 4.6 7 0.65 ± 0.9 Stenderetal. (2006) French fries (24) McDonald’s 124 French fries (19) Kentucky Fried Chicken 142 Mozaffarian et al. (2006) French fries 2036 French fries, frozen 30 Satchithanandaetal. (2004)
<table>
<thead>
<tr>
<th>Food Item</th>
<th>Trans Fatty Acid Content (wt.%)</th>
<th>% of Fatty Acids</th>
<th>g/100g Food</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frozen potato product (12)</td>
<td>24.738</td>
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<tr>
<td>Huang et al. (2006)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Potato wedges (6)</td>
<td>6.39 ± 0.8</td>
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</tr>
<tr>
<td>Slow et al. (1980)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Onion rings (1)</td>
<td>3.78</td>
<td></td>
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</tr>
<tr>
<td>Continued</td>
<td></td>
<td></td>
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<tr>
<td>Pies and turnovers (4)</td>
<td>3.78</td>
<td></td>
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</tr>
<tr>
<td>SDA (1995)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Milkshakes (4)</td>
<td>3.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slove et al. (1980)</td>
<td></td>
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<tr>
<td>Milkshakes (9)</td>
<td>0.050</td>
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<td></td>
</tr>
<tr>
<td>Onion rings (1)</td>
<td>3.12</td>
<td></td>
<td></td>
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<tr>
<td>Slow et al. (1980)</td>
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<tr>
<td>Milkshakes (9)</td>
<td>1.67</td>
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<td>Slove et al. (1980)</td>
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<tr>
<td>Milkshakes (9)</td>
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<tr>
<td>Slove et al. (1980)</td>
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<tr>
<td>Milkshakes (9)</td>
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<td>Slow et al. (1980)</td>
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<tr>
<td>Milkshakes (9)</td>
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<td>Slove et al. (1980)</td>
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<tr>
<td>Milkshakes (9)</td>
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<td>Slove et al. (1980)</td>
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</tr>
<tr>
<td>Onion rings (1)</td>
<td>1.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow et al. (1980)</td>
<td></td>
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<tr>
<td>Onion rings (1)</td>
<td>1.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow et al. (1980)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onion rings (1)</td>
<td>1.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow et al. (1980)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onion rings (1)</td>
<td>1.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>Calories</td>
<td>Fat</td>
<td>Fiber</td>
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<tr>
<td>-------------------------------------</td>
<td>----------</td>
<td>-------</td>
<td>--------</td>
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<tr>
<td>English muffins</td>
<td>212</td>
<td>2.1</td>
<td>6.2</td>
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<tr>
<td>Pancakes</td>
<td>162</td>
<td>2.1</td>
<td>6.2</td>
</tr>
<tr>
<td>Waffles</td>
<td>855.1</td>
<td>13</td>
<td>0.5</td>
</tr>
<tr>
<td>Granola</td>
<td>624.3</td>
<td>3.8</td>
<td>7.1</td>
</tr>
<tr>
<td>Cereal and almonds</td>
<td>294</td>
<td>4.2</td>
<td>6.5</td>
</tr>
<tr>
<td>Satchithana and almonds</td>
<td>294</td>
<td>4.2</td>
<td>6.5</td>
</tr>
<tr>
<td>Cereal bars</td>
<td>210</td>
<td>4.8</td>
<td>8.0</td>
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<tr>
<td>Cereal bars with strawberry</td>
<td>26.0</td>
<td>2.6</td>
<td>2.9</td>
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<tr>
<td>Fig bars</td>
<td>27</td>
<td>2.8</td>
<td>3.0</td>
</tr>
<tr>
<td>Apple cobbler bars</td>
<td>25.4</td>
<td>4.0</td>
<td>3.2</td>
</tr>
<tr>
<td>Oatmeal bars</td>
<td>22.4</td>
<td>4.4</td>
<td>3.2</td>
</tr>
<tr>
<td>Granola bars with brown sugar</td>
<td>22.4</td>
<td>4.4</td>
<td>3.2</td>
</tr>
</tbody>
</table>
M. TRANS-ISOMERS OF FATTY ACIDS IN HUMAN MILK AND INFANT FOODS

Whereas isomeric fatty acids may have no effects on an adult, in theory infants may be particularly vulnerable to the effects of factors that interfere with essential fatty acid metabolism and normal membrane structure (ILSI, 1997; Craig-Schmidt, 2001). Thus, it is important to know the trans-fatty acid content of foods consumed during this period of rapid development. Trans-fatty acids comprise 1%-7% of total fatty acids in human milk (Table 15.14). The amount of trans-octadecenoic acid (18:1t) appearing in the milk reflects the trans-content of the maternal...
diet consumed on the previous day (Aitchison et al., 1977; Craig-Schmidt et al., 1984). Friesen and Innis (2006) have found that the trans-fatty acid content of human milk has decreased from 7.1% in 1998 to 4.6% in 2005/2006. Infant formulas contain variable amounts of trans-fatty acids, with values of 0.1%-4.5% of total fatty acids reported (Picciano and Perkins, 1977; Hanson and Kinsella, 1981; Permamyer et al., 1990; O'Keefe et al., 1994; Jorgensen et al., 1995; Ali et al., 1996; Chardigny et al., 1996; Fernandez San Juan, 1996; Ratnayake et al., 1997) (Table 15.14a). One brand of infant formula analyzed by Hanson and Kinsella (1981) contained 15.7% of the fatty acids as trans-isomers, but all the others contained less than 2%. Three types of baby foods were analyzed for trans-fatty acids by Slover and Lanza (1979) and eight brands of dry infant cereals by Hanson and Kinsella (1981). All these products except the lamb broth (Slover and Lanza, 1979) contained less than 2% trans-fatty acids. More recent analysis (USDA, 1995) revealed that some U.S. infant foods contained greater than 5% trans-fatty acids. Thus, foods normally consumed by infants contain relatively low levels of trans-fatty acids.

In most cases, trans-isomeric fat in these products is no greater than that found in cow's milk (see Table 15.2).

V. ESTIMATES OF ISOMERIC FATTY ACIDS IN THE DIET

Several approaches can be taken in estimating isomeric fatty acids in the diet: (1) laboratory analysis of composite diets; (2) dietary analysis of diet records using food composition data such as those summarized above; (3) estimates based on trans-fatty acid
content of biological tissues; and (4) estimates based on “disappearance” or market share data. All these approaches have been used although most estimates are based on disappearance data. These methods and their use worldwide have been updated on estimates of isomeric fatty acids in the diet throughout the world. TABLE 15.11 Trans-Fatty Acid Content of a Typical Fast Food Meal Weight a (g) Trans-Fatty Acids b (g/100 g) Total Trans-Fatty Acids (g) Cheeseburger 215 0.59 1.27 Fries 106 0.60 0.64 Milkshake 290 0.67 0.20 Turnover 125 1.38 1.79 3.84 a Data from Table of Food Composition (Hamilton, E.M.N., et al. 1988). Nutrition: Concepts and Controversies, 4th ed., West, New York). b Data from Lanza, E., and Slover, H.T. (1981). Lipids 16: 260-267. As summarized in Table 15.10.

TABLE 15.12 Trans-Fatty Acid Content of Snack Items

<table>
<thead>
<tr>
<th>Country/Food Item</th>
<th>Trans-Fatty Acids (g/100 g)</th>
<th>Fat (g/100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States Potatoes (6)</td>
<td>0.27</td>
<td>4.6</td>
</tr>
<tr>
<td>United States Potatoes (9)</td>
<td>0.61</td>
<td>3.5-4.4</td>
</tr>
<tr>
<td>United States Potatoes (11)</td>
<td>0.61</td>
<td>3.5-4.4</td>
</tr>
<tr>
<td>United States Potatoes (6)</td>
<td>0.25</td>
<td>5.9</td>
</tr>
<tr>
<td>United States Potatoes (9)</td>
<td>0.26</td>
<td>5.9 ± 1.0</td>
</tr>
<tr>
<td>United States Potatoes (11)</td>
<td>0.29</td>
<td>5.9</td>
</tr>
<tr>
<td>United States Potatoes (6)</td>
<td>0.42</td>
<td>5.9</td>
</tr>
<tr>
<td>United States Potatoes (9)</td>
<td>0.42</td>
<td>5.9</td>
</tr>
<tr>
<td>United States Potatoes (11)</td>
<td>0.42</td>
<td>5.9</td>
</tr>
<tr>
<td>Canada Potatoes Unhydrogenated (2)</td>
<td>0.42</td>
<td>0.1-41.0</td>
</tr>
<tr>
<td>Canada Potatoes Unhydrogenated (3)</td>
<td>0.39</td>
<td>9.3-3.0</td>
</tr>
<tr>
<td>Canada Potatoes Unhydrogenated (6)</td>
<td>0.42</td>
<td>5.9</td>
</tr>
<tr>
<td>Canada Potatoes Unhydrogenated (9)</td>
<td>0.42</td>
<td>5.9</td>
</tr>
<tr>
<td>Germany Potatoes Unhydrogenated (10)</td>
<td>0.42</td>
<td>5.9</td>
</tr>
<tr>
<td>Germany Potatoes Unhydrogenated (12)</td>
<td>0.42</td>
<td>5.9</td>
</tr>
<tr>
<td>Germany Potatoes Unhydrogenated (13)</td>
<td>0.42</td>
<td>5.9</td>
</tr>
<tr>
<td>Germany Potatoes Unhydrogenated (14)</td>
<td>0.42</td>
<td>5.9</td>
</tr>
</tbody>
</table>

As summarized in Table 15.10.
<table>
<thead>
<tr>
<th>Country</th>
<th>Food Item</th>
<th>Trans Fat (g/100g)</th>
<th>Min</th>
<th>Max</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>Potato chips (1)</td>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Spain       | Potato chips (40) | 0.6±1.435 | 2±4 | 3Lake et al. (1996) | 0.3±0.80 | 5±0.330 | 35
| New Zealand | Potato chips (3) | 0.3 |      |      |      |
| Denmark     | Chips (5) | 0.822 | 0.822 | 2.9 | 37 | 6
| Spain       | Chips (40) | 0.29 |      |      |      |
| New Zealand | Chips (3) | 0.3 |      |      |      |
| United States | Chips (5) | 0.822 | 0.822 | 2.9 | 37 | 6
| Spain       | Chips (40) | 0.29 |      |      |      |
| New Zealand | Chips (3) | 0.3 |      |      |      |
| Canada      | Chips (5) | 0.733 | 0.733 | 69.9 | 15 |
| United States | Tortilla chips (1) | 17.5 | 25.6 | 6Satcithan et al. (2004) | 19.4 | 1.4 | 33.5
| Canada      | Chips (5) | 0.733 | 0.733 | 69.9 | 15 |
| United States | Tortilla chips (8) | 0.017 | 1Mozaifar et al. (1993) | 0.9 | 1.6 | 17.4
| United States | Cheese snacks (1) | 33.4 | 33.4 | 6
| United States | Cheese snacks (6) | 1.028 | 1.22 | 3-46 | 0
| United States | Cheese snacks (2) | 10.0 | 25.8 | 17.9±11.2 | 31.3-32.2 | 2
| United States | Cheese snacks (4) | 23.5 | 53.3 | 9USDA (1995) | 19.5 |
| United States | Cheese snacks (2) | 10.0 | 25.8 | 17.9±11.2 | 31.3-32.2 | 2
| United States | Cheese snacks (2) | 35.8 | 48.0 | 41.9Enig et al. (1993) | 3.0 |
| United States | Doughnuts (1) | 3.0 | 3.0 | 4
| United States | Doughnuts (2) | 32.5 | 35.3 | 7USDA (1995) | 30.3-34.7 |
| United States | Doughnuts, cake (4) | 10.1 | 134.3 | 39.1-31.4 | 31.4Enig et al. (1990a) | 3.0 |
| United States | Doughnuts (2) | 32.5 | 35.3 | 7USDA (1995) | 30.3-34.7 |
| United States | Doughnuts, cake (5) | 3.8 | 28.2 | 21.8-50.1 | 15.1-25.2 | 2
| United States | Doughnuts, yeast (4) | 2.3 | 33.1 | 21.3-12.4 | 7.19.5-32.4 | 4
| United States | Doughnuts (5) | 25.8 | 32.7 | 29.1±2.9 | 16.6-29.6 | 6
| United States | Doughnuts (13) | 3.9 | 42.7 | 29.613.5 | 5Elig et al. (2002) | 3.5 |
| United States | Doughnuts (13) | 3.9 | 42.7 | 29.613.5 | 5Elig et al. (2002) | 3.5 |
| United States | Chips (13) | 3.9 | 42.7 | 29.613.5 | 5Elig et al. (2002) | 3.5 |
| United States | Chips (13) | 3.9 | 42.7 | 29.613.5 | 5Elig et al. (2002) | 3.5 |
| United States | Chips (13) | 3.9 | 42.7 | 29.613.5 | 5Elig et al. (2002) | 3.5 |
Germany Crackers (2) trace 5.6 2.8 Ratanayake et al. (1993) Canada Crackers Unhydrogenated (1) — 17.9 Hydrogenated (7) 13.8 35.4 25.8 92.2 — 33.0 Elias et al. (2002) Canada Crackers (13) 23.5 51.3 40.3 ± 8.5 USDA (1995) United States Crackers (9) 11.6 39.9 32.6 ± 9.6 11.0 — 24.5 Ali et al. (1996) United States Crackers (3) 12.8 42.9 23.3 Peanut butter sandwich (1) 16.5 29.5 ± 0.6
ck
er
s
0.66
±
0.2

Lake et al. (1996) New Zealand Crackers (5) 1.23.92.0 ± 1.18 - 25 Richards et al. (1997) New Zealand Crackers (1) 0.71 23.8 Monge Rojas et al. (2005) g Costa Rica Crackers 0.24 Pfalzgraf et al. (1993) Germany Popcorn (1) 0.90 USD (1995) United States Popcorn (5) 26.9 35.2 31.3 ± 3.0
- 37.2 Mozaffarian et al. (2006) United States Popcorn, microwave 11

Oetal. (1998c) h Europe Popcorn (5) 0.04 34.82 Elias et al. (2002) d Canada Popcorn (2) 44.14 7.345.7 Pfalzgraf et al. (1993) Germany Others snacks Unhydrogenated (4) 0.41 20.8 Hydrogenated (2) 9.92 20.215.1 Fernandez San Juan (1996) Spain Others snacks (20) 0.1 ± 0.136.9 ± 2.9 a Number of samples analyzed appears in parentheses following food item. b Percentage of total fatty acids. Only one brand contained significant amounts of trans fatty acids. One other brand contained 0.3%; the other four contained negligible amounts. d Data expressed as g/100 g of fat. e Data expressed as percentage of corresponding triglyceride. f Enig et al. (1983). J. Am. Oil Chem. Soc. 60: 1788 - 1795. Data expressed as percentage of methyl esters. g Data expressed as g /100 g of food. h Number of European countries from which samples were analyzed appears in parentheses following food.
o wing food item. Values presented a range. Data expressed as percentage of methyl esters.

**TABLE 15.13**

Trans-Fatty Acid Content of Bread, Cakes, Sweets, and Miscellaneous Processed Foods

<table>
<thead>
<tr>
<th>Reference Country</th>
<th>Food Item</th>
<th>Trans-Fatty Acids (%)</th>
<th>Min</th>
<th>Max</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enig et al. (1983) b</td>
<td>United States Breads and rolls (10/9)</td>
<td>0/0.2 27.9 10.1/11.2</td>
<td>Breading mixes, fried crusts (8/5)</td>
<td>0/12.1 33.5 12.9/20.6</td>
<td>Cakes (4)</td>
</tr>
<tr>
<td>Laryea et al. (1988)</td>
<td>Germany Nut-nougat creams (12)</td>
<td>0.35 12.35 7.2 ± 3.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Won and Ahn (1990) d</td>
<td>Korea Cookies and cakes</td>
<td>1.3 Animal food, fried and sauteed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boatella et al. (1993a)</td>
<td>Spain Assorted bakery products (83)</td>
<td>1.6 ± 1.6</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Ratnayake et al. (1993)</td>
<td>Canada Bread Unhydrogenated fat (6)</td>
<td>0 2.9 1.4 ± 1.3 Hydrogenated fat (1)</td>
<td>15.7 Mufns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pfalzgraf et al. (1993)</td>
<td>Germany Bakery products (13)</td>
<td>0 27.9 7.4 ± 8.3 Sweets Nut/nougat creams (5)</td>
<td>0.5 15.2 6.6 ± 6.6</td>
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</table>
TABLE 15.13

(Continued)

<table>
<thead>
<tr>
<th>Reference Country</th>
<th>Food Item</th>
<th>Trans-Fatty Acids (%)</th>
<th>Min</th>
<th>Max</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ovesen and Leth (1995)</td>
<td>Denmark Pastry 8</td>
<td>14 10 Croissants 8 14 11</td>
<td>Cookies 3 17 8 Pizza 0 0 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USDA (1995)</td>
<td>United States Bread (6)</td>
<td>1.5 25.5 12.8 ± 9.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Biscuits (2)</td>
<td>22.9 36.5 29.7 ± 9.6</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Muffins (1)</td>
<td>51.9 Rolls (4) 2.2 25.6 10.0 ± 10.6</td>
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</tr>
<tr>
<td></td>
<td>Taco shells (1)</td>
<td>31.5 Tortillas (1) 16.6 Cereals, breakfast (6) 4.2 40.3 20.7 ± 13.2 Cakes (6) 3.9 28.3 18.5 ± 9.5 Snack cakes (1) 21.6 Sweet rolls (1) 14.3 Danish pastry (1) 0.5 Cookies (7) 18.7 37.7 29.4 ± 7.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Candies (3)</td>
<td>0.3 29.1 12.9 ± 14.7 Frostings (6) 19.7 24.7 21.7 ± 2.1 French fries (7) 7.3 34.2 20.6 ± 10.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ali et al. (1996)</td>
<td>United States Peanut butter cookies 1.7 Biscotti 3.1 Cereal with raisins 15.0 Chicken pie 25.5 Turkey with gravy dressing 13.9 Beef ravioli with sauce 5.0 Chili macaroni 3.8 Breaded fish fillets 16.6 Taco dinner 29.7 Chili without beans 5.9</td>
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<td>De Greyt et al. (1996)</td>
<td>Belgium Assorted bakery products &lt;5% trans (12) n.d. 4.1 1.5 ± 1.5 &gt;5% trans (15) 5.1 18.8 9.6 ± 3.8</td>
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<td>Demmelmair et al. (1996)</td>
<td>Germany Chocolate spreads (6) 0.7 11.1 6.2 ± 3.6 Peanut butter (3) 0 0.3 0.1 ± 0.1 Vegetarian spreads (6) 0.1 0.4 0.2 ± 0.1</td>
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<td>Fernandez San Juan (1996)</td>
<td>Spain Assorted bakery products (30) 9.4 ± 8.9 Cookies (42) 1.1 ± 1.1 Cakes (50) 3.1 ± 2.0</td>
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<td>Creams (15) 1.8 ± 0.4 Pizzas (20) 3.1 ± 4.0</td>
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<td>Lake et al. (1996)</td>
<td>New Zealand Pastry (5) 3.6 7.5 6.2 ± 1.8 Cakes (5) 2.6 8.4 5.2 ± 2.1 Cookies and crackers (5) 1.1 3.5 2.0 ± 1.0</td>
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<td>Richardson et al. (1997)</td>
<td>New Zealand White bread 2.2 Pastry 5.6 Chocolate coated cookies 1.7</td>
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<td>Plain sweet cookies 4.5</td>
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<td>Meat pies 3.9</td>
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<td>Reference Country</td>
<td>Food Item</td>
<td>Trans-Fatty Acids (%)</td>
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<tr>
<td>van Erp-baart et al. (1998)</td>
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<td>0.05 17.35</td>
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<tr>
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<td>Cookies and biscuits lowest in trans (14)</td>
<td>0.12 12.63</td>
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<td>highest in trans (13)</td>
<td>1.45 27.96</td>
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<td>Cake and sweet pastry lowest in trans (14)</td>
<td>0.39 16.63</td>
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<td>highest in trans (13)</td>
<td>3.66 33.32</td>
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<td>Croissants (11) 3.03 14.55</td>
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<td>Cream crackers (4) 9.10 29.08</td>
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<td>Parcerisa et al. (1999)</td>
<td>g Spain Bakery products, commercial (15)</td>
<td>0.60 11.05</td>
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<tr>
<td>Innis et al. (1999)</td>
<td>h Canada White bread (8) 1.33 34.91 8.5</td>
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<td>Whole wheat bread (8) 1.03 36.31 15.6</td>
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<td>Croissants (3) 5.54 40.91</td>
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<td>Crackers (14) 23.51 51.31 40.31</td>
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<td>Croutons (3) 22.91 51.61</td>
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<td>Cake mixes (3) 28.71 30.11 29.61</td>
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<td>Cookies (19) 1.41 45.71</td>
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<td>Pie shells (6) 1.91 45.61 25.81</td>
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<tr>
<td>Elias et al. (2002)</td>
<td>h Canada Bread (12) 1.03 36.31 18.0 ± 15.5</td>
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<td></td>
<td>Rolls (14) 0.35 35.31 8.9 ± 10.4</td>
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<td></td>
<td>Bagels (3) 1.21 2.51 2.0 ± 0.7</td>
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<td></td>
<td>Croissants (3) 5.54 40.91 18.1 ± 19.7</td>
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<td>Danish pastry (2) 41.71 59.21 50.51</td>
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<td>Cake mix (5) 24.91 36.21 30.0 ± 4.1</td>
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<td>Tortilla, K our (2) 27.31 32.71 30.0</td>
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<td></td>
<td>Pastry shells (5) 1.91 45.61 23.6 ± 21.2</td>
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<td></td>
<td>Granola bars (4) 0.71 17.01 8.7 ± 6.7</td>
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<td></td>
<td>Pretzels (2) 0.91 23.21 12.01</td>
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<tr>
<td></td>
<td>Peanut butter (2) 1.61 6.71 4.21</td>
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<td>Vicario et al. (2003)</td>
<td>Spain Chocolate coated cookies (4) 0.38 ± 0.26</td>
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<td>Butter cookies (3) 1.41 ± 0.23</td>
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<td>Wholemeal cracker (3) 35.54 ± 1.48</td>
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<td>Tea pastry (2) 1.01 ± 0.57</td>
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<td>Croissant (4) 5.94 ± 0.69</td>
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<td>Sponge cakes (2) 2.10 ± 0.08</td>
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<td>Swiss roll (1) 0.15</td>
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<td>Chocolate cake (5) 4.10 ± 1.50</td>
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<tr>
<td>Satchithanandan et al.</td>
<td>(2004) United States Dinner rolls 16.6</td>
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<td></td>
<td>Crescent rolls, reduced fat 19.3</td>
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<td></td>
<td>Biscuits, butter-K avored 32.7 34.4</td>
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<td></td>
<td>Flaky biscuits 20.8</td>
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<td></td>
<td>Buttermilk biscuits 34.1</td>
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<td></td>
<td>Biscuits, Texas-style 26.2</td>
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<td></td>
<td>Cake rolls, iced and filled 15.3 34.5</td>
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TABLE 15.13

(Continued)
<table>
<thead>
<tr>
<th>Reference Country</th>
<th>Food Item</th>
<th>Trans-Fatty Acids (%)</th>
<th>Min</th>
<th>Max</th>
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<tbody>
<tr>
<td>Avg</td>
<td>Cake, chocolate covered</td>
<td>6.6</td>
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<td></td>
<td>Cake, peanut butter covered</td>
<td>0.9</td>
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<td>Sponge cake, filled</td>
<td>0.0</td>
<td>20.8</td>
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<td></td>
<td>Mini cake snacks, iced</td>
<td>10.9</td>
<td></td>
<td></td>
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<td></td>
<td>Cornbread</td>
<td>32.1</td>
<td></td>
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<tr>
<td></td>
<td>Tortillas</td>
<td>19.5</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Flour tortillas</td>
<td>1.9</td>
<td>18.0</td>
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<tr>
<td></td>
<td>Corn tortillas</td>
<td>0.0</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Taco dinner kit</td>
<td>16.3</td>
<td>24.9</td>
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<tr>
<td></td>
<td>Pizza kit</td>
<td>22.8</td>
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<td>Monge-Rojas et al. (2005)</td>
<td>d,i Costa Rica</td>
<td>White bread</td>
<td>0.041</td>
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<td>Cookies</td>
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<td>Crème-filled cookies</td>
<td>1.027</td>
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<td>Chocolate cookies</td>
<td>1.161</td>
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<td>Huang et al. (2006)</td>
<td>e United States</td>
<td>Crackers, grocery</td>
<td>0.66 ± 0.22</td>
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<td></td>
<td>Muffin, grocery</td>
<td>0.0</td>
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<td></td>
<td>Biscuit mix, grocery</td>
<td>1.82 ± 0.11</td>
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<td></td>
<td>Cookies, grocery</td>
<td>0.51 ± 0.01</td>
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<td></td>
<td>Cookies, fast food</td>
<td>2.30 ± 0.34</td>
<td>3.18 ± 0.10</td>
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<td></td>
<td>Biscuits, fast food</td>
<td>8.35 ± 0.29</td>
<td>10.30 ± 1.67</td>
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<td>Mozaffarian et al. (2006)</td>
<td>United States</td>
<td>Pie</td>
<td>28</td>
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<td></td>
<td>Danish or sweet roll</td>
<td>Doughnuts</td>
<td>25</td>
<td>25</td>
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<td>Cookies</td>
<td>26</td>
<td>Cake</td>
<td>16</td>
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<td>Brownie</td>
<td>21</td>
<td>Tortillas</td>
<td>25</td>
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<td>Peanut butter</td>
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<tr>
<td>a Number of total brands analyzed.</td>
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<tr>
<td>b Data as classified by the author: minimum and average values for total number of brands analyzed followed by minimum</td>
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<tr>
<td>and average values for items excluding those that contained no detectable amounts of trans-fatty acids. Values include 18:1t plus isomeric forms of 18:2.</td>
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<tr>
<td>c Excluding fast food French fries. See Table 15.10.</td>
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<tr>
<td>d Trans-18:1 content only.</td>
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<tr>
<td>e Data expressed as percentage of corresponding triglyceride.</td>
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<tr>
<td>f Number of European countries from which samples were analyzed appears in parentheses following food item. Values presented as range.</td>
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<tr>
<td>g Bakery products include 1 Swiss cake, 3 Swiss rolls stuffed with chocolate, 1 sponge cake, 3 sponge cakes filled with choco</td>
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</table>
late, 2 doughnuts, 1 doughnut filled with chocolate, 1 biscuit coated with chocolate, and 3 cakes filled with chocolate. Values presented as range. Data expressed as percentage of methyl esters.

h Data expressed as g/100 g of fat.

i Data expressed as g/100 g of food.

A. ANALYSIS OF COMPOSITE DIETS

Estimates obtained by analysis of composite diets collected from a given population have the advantage of being based on data obtained by analytical methods in the laboratory. This method suffers from the fact that the diets or populations analyzed may not be representative of the population as a whole. A number of investigators (Aitchison et al., 1977; Åkesson et al., 1981; Table 15.14

<table>
<thead>
<tr>
<th>Trans-Fatty Acid Content of Human Milk</th>
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<tbody>
<tr>
<td>Aitchison et al. (1977) c, U.S., human milk (11)</td>
</tr>
<tr>
<td>Picciano and Perkins (1977) d, U.S., human milk (3)</td>
</tr>
<tr>
<td>Clark et al. (1980) e, U.S., human milk (11)</td>
</tr>
<tr>
<td>Hanson and Kinsella (1981) U.S., human milk (1) tr</td>
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<tr>
<td>Hundrieser et al. (1983) d, U.S., human milk (10)</td>
</tr>
<tr>
<td>Craig-Schmidt et al. (1984) d, U.S., human milk (8)</td>
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<tr>
<td>Chappell et al. (1985) f, Canada, human milk (14)</td>
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<tr>
<td>Finley et al. (1985) e, U.S., human milk (57)</td>
</tr>
<tr>
<td>Koletzko et al. (1988) c, Germany, human milk (15)</td>
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</tbody>
</table>
Koletzko et al. (1991) c Nigeria, human milk (10) 0.79
10.29 1.20
Boatella et al. (1993b) Spain, human milk (38) 1.2
Chardigny et al. (1995) g France, human milk (10) 1.33 4.4
2.27
Chen et al. (1995) h Canada, human milk (198) 7.19 ± 3.03
Jorgensen et al. (1995) i Denmark, human milk (11) 1.6 4.5
2.5
Laryea et al. (1995) c Sudan, human milk (77) 0.23 1.45
0.61 ± 0.26
0.57 c
Chen et al. (1997) c China, human milk Chongqing (33) 0.22
± 0.06 Hong Kong (51) 0.88 ± 0.61
Genzel-Boroviczeny et al. (1997) c Germany, human milk (38)
1.13 (0.46) j
Innis and King (1999) Canada, human milk (103) 7.1 ± 0.32
Dlouhy et al. (2002) Czech, human milk (35) 1.84 9.78 4.22
± 1.87
Mosley et al. (2005) U.S., human milk (81) 2.5 13.8 7.0 ±
2.3
Mosley et al. (2006) d U.S., human milk (4) 3.0 ± 0.15
± 0.32 November 2004-March 2005 (24) 6.2 ± 0.48
April-August 2005 (24) 5.3 ± 0.49 September 2005-January
2006 (39) 4.6 ± 0.32

a Number of subject analyzed appears in parentheses
following food item.

b Percentage of total fatty acids.

c Includes trans-isomers of 14:1, 18:1, and 18:2.

d Trans-18:1 content only.
Include trans-isomers of 16:1 and 18:1.

f Includes trans-isomers of 18:1 and 18:2.

g Includes trans-isomers of 18:1, 18:2, and 18:3.

h Includes trans-isomers of 14:1, 16:1, 18:1, 18:2, and 18:3.

i Includes trans-isomers of 16:1, 18:1, and 18:2.

j Median (interquartile ranges).

**TABLE 15.14a**

Trans-Fatty Acid Content of Infant Formula and Other Infant Foods

<table>
<thead>
<tr>
<th>Reference Food Item a</th>
<th>Trans-Fatty Acids (%)</th>
<th>Fat (%)</th>
<th>Min</th>
<th>Max</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picciano and Perkins (1977) c</td>
<td>U.S. infant formula (3)</td>
<td>0.1</td>
<td>1.3</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Hanson and Kinsella (1981)</td>
<td>U.S. infant formula (11)</td>
<td>0.8</td>
<td>2.0</td>
<td>1.2</td>
<td>6.0</td>
</tr>
<tr>
<td>Permanyer et al. (1990) d</td>
<td>Spanish infant formula “Preterm” formula (3)</td>
<td>1.2</td>
<td>2.6</td>
<td>2.1 ± 0.8</td>
<td>“0-6 month” formula (10)</td>
</tr>
<tr>
<td>Koletzko (1991)</td>
<td>German infant formula (28)</td>
<td>0.2</td>
<td>4.6</td>
<td></td>
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<tr>
<td>O'Keefe et al. (1994) e</td>
<td>U.S. infant formula (10)</td>
<td>0.2</td>
<td>1.3</td>
<td>0.8 ± 0.3</td>
<td></td>
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<tr>
<td>Jorgensen et al. (1995) f</td>
<td>Danish infant formula Standard formula (6)</td>
<td>1.4</td>
<td>4.2</td>
<td>2.7 ± 1.1</td>
<td>Special formula (7)</td>
</tr>
<tr>
<td>Chardigny et al. (1996b) g</td>
<td>French infant formula Premature formula (2)</td>
<td>1.3</td>
<td>2.5</td>
<td>1.9 ± 0.8</td>
<td>“0-5 month” formula (9)</td>
</tr>
<tr>
<td>Fernandez San Juan (1996) f</td>
<td>Spanish infant formula (20)</td>
<td>2.3</td>
<td>± 1.1</td>
<td>26.5 ± 3.2</td>
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</tbody>
</table>
Ratnayake et al. (1997) g Canadian infant formula Powdered infant formula (14) 0.6 2.5 1.4 Liquid infant formula (12) 0.9 3.1 1.9

Slover and Lanza (1979) U.S. baby food (3) 0.2 7.6 3.2 5.8

Hanson and Kinsella (1981) U.S. dry infant cereal (8) 0.3 0.6 0.5

USDA (1995) f U.S. infant food Vegetable and beef dinner, strained (2) 4.7 5.6 5.1 ± 0.6 2.9 ± 0.2

Holub (1999) Canadian baby food Baby biscuits 37 Infant cereals 23

a Number of brands analyzed appears in parentheses following food item.
b Percentage of total fatty acids.
c 18:1t only.
d Includes trans-isomers of 16:1, 18:1, 18:2, and 18:3.
e No 18:1t reported; values include trans-isomers of 18:2 and 18:3.
f Includes trans-isomers of 16:1, 18:1, and 18:2.
g Includes trans-isomers of 18:1, 18:2, and 18:3; does not include conjugated 18:2.

Craig-Schmidt et al., 1984; van den Reek et al., 1986b; Enig et al., 1990a) have used this approach, and the results are summarized in Table 15.15. Relatively, “raw” data are presented to allow the reader to see the variation both between the diets of individuals and within the day-to-day diets of a given individual. Aitchison et al. (1977) reported that 3-day self-chosen diet collections from 11 adult subjects in the United States contained an average of 5.0% of the fatty acids as trans-isomers, with a range of 1.3%-8.3%. The trans-fatty acid content of the 33 diet collections ranged from 0.0 to 9.9 g/day,
<table>
<thead>
<tr>
<th>Reference</th>
<th>Subjects</th>
<th>Nanomolar</th>
<th>1-1000%</th>
<th>Daily Portions</th>
<th>Dietary Trans-Fatty Acids Concentration (%)</th>
<th>Daily Intake (g/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aitchison et al. (1977) (self-selected diets of lactating women)</td>
<td>Subject</td>
<td>1</td>
<td>3</td>
<td>6.98</td>
<td>0.9–4.2</td>
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<td></td>
<td></td>
<td>2</td>
<td>3</td>
<td>6.13</td>
<td>1.8–3.5</td>
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<tr>
<td></td>
<td></td>
<td>3</td>
<td>3</td>
<td>8.27</td>
<td>4.4–5.2</td>
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<td></td>
<td></td>
<td>4</td>
<td>3</td>
<td>5.23</td>
<td>2.2–4.8</td>
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<td></td>
<td></td>
<td>5</td>
<td>3</td>
<td>1.30</td>
<td>0.0–3.1</td>
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<td></td>
<td></td>
<td>6</td>
<td>3</td>
<td>3.54</td>
<td>1.0–5.5</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
<td>3</td>
<td>8.15</td>
<td>0.0–9.9</td>
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</tr>
<tr>
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<td>8</td>
<td>3</td>
<td>5.07</td>
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<tr>
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<td>9</td>
<td>3</td>
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<td>10</td>
<td>3</td>
<td>2.60</td>
<td>1.4–8.7</td>
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<tr>
<td></td>
<td></td>
<td>11</td>
<td>3</td>
<td>3.69</td>
<td>1.4–2.3</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td>5.03</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Åkesson et al. (1981) (Swedish diets) b
- 1968, men (10) 70 5.0 4.9
- 1968, women (10) 70 5.0 2.8
- 1975, women (6) 36 5.1 3.0
- 1978, vegans (6) 24 1.8 0.9
- 1980, lactovegetarians (6) 24 3.9 3.0
Craig-Schmidt et al. (1984) (experimental diets)

Made with hydrogenated fat
Day 1 12.31 11.04
Day 2 13.15 10.24
Day 3 7.65 6.68
Day 4 8.82 6.91
Day 5 17.11 13.72
5-Day mean 11.81 9.72

Made with nonhydrogenated fat
Day 1 0.73 0.64
Day 2 0.87 0.59
Day 3 1.04 0.88
Day 4 1.30 1.17
Day 5 1.07 1.00
5-Day mean 1.00 0.86

Van den Reek et al. (1986b) (diets of U.S. adolescent girls)

Subject
1 7 2.33–7.58 1.13–4.48
2 7 5.01–9.15 1.28–3.93
3 6 1.85–9.05 1.53–7.04
4 7 4.06–17.16 1.06–6.95
5 7 1.98–12.00 0.45–5.72
6 7 2.43–7.48 1.03–6.21

with both minimum and maximum values exhibited by the same subject (see Table 15.15). Similar values for Swedish diets were reported by Åkesson et al.
Trans-octadecenoic (18:1t) acid was 5.0%, 3.9%, and 1.8% of dietary fatty acids in the normal, lactovegetarian, and vegan diets of Swedish adults. Daily consumption ranged from 0.9 g/day for the vegans to 4.9 g/day for the male subjects. These values are in agreement with those of van den Reek et al. (1986b), who found that the amount of trans-octadecenoic acid (18:1t) in the diets of eight adolescent girls collected for a 7-day period ranged from 3.5% to 8.2% of total fatty acids, with an average of 5.3%. The total trans fatty acid content of the diets on 56 individual days in this study ranged from 1.9% to 17.2% of total fatty acids, with an average of 6.5% (see Table 15.15). The average daily consumption of 3.1 g/day (range 0.45-7.97 g/day) is also in agreement with the two earlier studies. In comparing these studies, it is important to note the large variation both within the diets of the same subject and between subjects. Taken collectively, trans-fatty acid intake in these studies ranged from 0.45 g/day in an adolescent girl consuming 500 kcal, with 33% of these calories from fat (van den Reek et al., 1986b), to 9.9 g/day in a lactating woman consuming 2185 kcal, with 42% of calories from fat (Aitchison et al., 1977). Possible extremes in trans-fatty acid consumption have been further defined by the analysis of experimental diets in which diets made with hydrogenated sources of fat were compared to diets made with nonhydrogenated sources of fat (see Table 15.15).

In the study by Craig-Schmidt et al. (1984), one day’s diet made with nonhydrogenated sources of fat provided 0.59 g of trans-fatty acids compared to 13.72
g in a diet made with only hydrogenated fat. As percentage of total fatty acids, 18:1t ranged from 0.73% in a “nonhydrogenated” diet to 17.1% in a “hydrogenated” diet (Craig-Schmidt et al., 1984). Because all the diets were designed for lactating women, total calories and other nutrients were kept relatively constant. It is thus easy to see from these studies that extremes can exist in trans-fatty acid content of both self-selected diets and experimental diets. Enig et al. (1990a) reported that recent analyses of total diet composites show a range of 6%-12% of the total fatty acids as trans-fatty acids. This range is well within the extremes defined by the experimental diets of Craig-Schmidt et al. (1984).

B. ANALYSIS OF DIETARY RECORDS USING FOOD COMPOSITION DATA

Diet records and dietary recall methods can also be used to estimate trans-fatty acid consumption.

Using data obtained by a 1-day dietary recall followed by a 2-day dietary record and assuming that the average trans-fatty acid content of fats consumed in 1977 was 5.6%, Senti (1985) calculated per capita daily trans-fatty acid consumption to be 4.5-6.5 g/day.

TABLE 15.15

(Continued)

Reference No. of Daily Portions Dietary Trans-Fatty Acids
Conc. (%) Intake (g/day)

Van den Reek et al. (Continued)

Subject
7 7 3.07-7.77 1.20-4.20
8 7 4.04-10.67 2.69-7.97
Mean ± SEM 6.53 ± 0.42 3.14 ± 0.26

Enig et al. (1990a) (composites of U.S. diets) d 6–12

a Expressed as percentage of total fatty acids.
b Number of subjects appears in parentheses.
c Designed for U.S. lactating women.
d Primary data were not given. From 7-day diet records and published trans-fatty acid values in foods, van den Reek et al. (1986a) estimated the dietary levels of trans-octadecenoic acid (18:1t) in the diets of eight healthy white adolescent girls to be 5.3% of total fatty acids. This value was the same as that determined by laboratory analysis of diets collected by the duplicate portion technique (van den Reek et al., 1986b). This value is lower than values reported by Enig et al. (1990a) in which diet history and analytically determined food composition data were used to estimate per capita trans-fatty acid intake.

Calculations based on data from individual diets developed by the USDA to comply with the Dietary Goals and known trans-fatty acid values for individual foods gave a range of 7.2%-20% of the total fat as trans-fatty acids. Values for fat intake for participants of the Lipid Research Clinic screening study were used in combination with an estimated dietary trans-fatty acid intake (Enig et al., 1990a).

For adult males with fat intakes of 40-250 g/person per day, estimates of 2.4-20.6 g/person per day for total trans-fatty acid intake were obtained; for adult females consuming 31-179 g fat per day, trans-fatty acid intake was estimated to be 1.9-14.3 g/person per day. Ranges of energy intakes
for these subjects were not reported by Enig et al. (1990a). Trans-fatty acid intake reported per 1000 kcal would be useful comparing results from various studies and in accounting for the extreme variations seen in these trans-isomer intake estimations.

C. ESTIMATES BASED ON TRANS-FATTY ACID CONTENT OF BIOLOGICAL TISSUES

Another approach to the estimation of the consumption of dietary isomeric fatty acids is to extrapolate from the concentration found in biological tissues. Craig-Schmidt et al. (1984) estimated that the usual diets of the lactating women in their study contained 7.8% of the fatty acids as the trans isomers of octadecenoic acid (18:1t; Table 15.16). This estimate was based on extrapolation of the relationship between 18:1t in the maternal diet vs. 18:1t in human milk samples. The average content of 18:1t in the milk of the subjects on day 1 of the experiment was believed to reflect the content of the self-chosen diets from the previous day. A similar approach was taken by Enig et al. (1990a), who used the concentration of trans-fatty acids in human adipose tissue to estimate dietary trans-fatty acids. Analysis of human adipose tissue provides an indirect method of estimating dietary fatty acid isomer intake, because these isomers are not synthesized by humans. Adipose tissue fatty acids have a long half-life, and therefore the concentrations of trans-fatty acids in adipose tissue are believed to reflect the dietary trans-fatty acid content. Studies by Heckers et al. (1979) in Germany, Ohlrogge et al. (1981) and Ohlrogge (1983) in the United States, and Thomas et al. (1981) in the United Kingdom showed a range of 1.0%–11.6%
total trans-fatty acids in adipose tissue. However, as Enig et al. (1990a) point out, a 1:1 relationship between dietary and adipose tissue does not necessarily hold true, because some of the trans-fatty acids are metabolized, and therefore the concentration of trans-fatty acids in adipose tissue would be expected to be lower than the concentration of trans-fatty acids in the diet.

TABLE 15.16

Estimates of Dietary Trans-Fatty Acids Based on Concentration of Trans-Fatty Acids in Human Biological Tissues

Craig-Schmidt et al. (1984) Human milk 7.8

Enig et al. (1990a) Adipose tissue a 2.4–11.1


on human adipose tissue trans-fatty acid levels in combination with an equation expressing the relationship between dietary 18:1t and adipose tissue levels in rats and mice. The animal data were taken from several sources (Aln-Slater and Aftergood, 1979; Bonaga et al., 1980; Moore et al., 1980; Royce et al., 1984; Selenskas et al., 1984; Ostlund-Lindqvist et al., 1985; Petterson and Opstvedt, 1988). Using a range of 2.0%–5.8% of total fatty acids as 18:1t in adipose tissue (Ohlrogge et al., 1981), Enig et al. (1990a) estimated that U.S. diets contain 2.4%–11.1% of total fatty acids as trans 18:1 isomers (see Table 15.16).

D. ESTIMATES BASED ON “DISAPPEARANCE” DATA
Until recently, the most commonly used method of estimating trans-fatty acid consumption has been based on fat disappearance or market size/share data in combination with product composition data. The estimate of Kummerow (1975) that the total trans-fatty acid intake from visible fat is approximately 8% was based on 1971 USDA household consumption data and typical trans-fatty acid compositional data. In 1971, margarine represented 7%, shortening 13.2% and cooking and salad oils 12.4% of the visible fat intake. These data were combined with typical values for sources of hydrogenated fat, that is, stick margarine containing 25%-35%, tub margarines 15%-25%, shortening 20%-30%, and salad oils 0%-15% trans-fatty acids. The small contribution of isomeric fatty acids from meat and dairy products was not included in this estimate. Several other researchers using similar approaches calculated comparable values for percent of fat as trans-fatty acid; for example, 8% (Enig et al., 1978) and 6.8% (Emken, 1981). Elson et al. (1981) stated that data provided by the ISEOs indicate that the dietary fat supply available for human consumption consists of 5%-15% trans-fatty acids. Senti (1985) estimated that total per capita consumption of dietary trans-fatty acids in the United States is 10.2 g/day (Table 15.17). When Senti (1985) adjusted this value to account for wastage of frying oils and separable fat of retail beef cuts, a value of 8.3 g/day trans-fatty acid consumption was obtained. This value is only slightly greater than the value of 7.6 g/day estimated by Hunter and Applewhite (1986). On the other hand, Enig
et al. (1990a) contend that Hunter and Applewhite (1986) overestimated wastage in their calculations and estimate that the average person in the United States consumes 12.8 g/day of trans-fatty acids. The major difference between the estimate of Enig et al. (1990a) and earlier estimates is in the category of shortening, for which both the fat intake as shortening (26.5 g/day) and average per centage of trans-isomer concentration are high in comparison to the other estimates in Table 15.17.

Estimates for trans-fatty acid intake for Canada and the United States are higher than the 4.5-6.5 g/day reported by Heckers et al. (1979) for Germany and 6.5 g/day by Enig et al. (1984) for Israel but lower than the value of 17 g/day reported by Brussaard (1986) for The Netherlands. In general, estimates of average trans-fatty acid consumption using disappearance data are higher as one might expect than estimates obtained by laboratory analysis of composite diets (see Table 15.15). However, extremes in individual intakes, as the data in Table 15.15 show, may extend well beyond these estimates of average intake. Some investigators (Brisson, 1981; Craig-Schmidt et al., 1984; Senti, 1985; Hunter and Applewhite, 1986; Enig et al., 1990a) have tried to account for the contribution of animal fats as well as that hydrogenated vegetable oils to total trans-fatty acid intake (see Table 15.17). Brisson (1981) estimated that about 94% (or 8.5 g of a total of 9.1 g) of trans-fatty acids per day is due to hydrogenated vegetable oils, with the remainder being due to fats of ruminant origin. The estimate of Senti (1985) for total trans-fatty acid intake (10.2 g/day) is only slightly greater than that of
Brisson (1981), but the relative contribution of animal and dairy fats to the total is greater. The average per capita daily consumption of trans-fatty acids of 7.6 g determined by Hunter and Applewhite (1986) is less than the estimates of Brisson (1981) or Senti (1985), which were based on food disappearance data without a wastage factor for discarded fat. The estimate of Hunter and Applewhite (1986) was based primarily on product composition and market share data provided by

TABLE 15.17
Estimated Per Capita Daily Consumption of Trans-Fatty Acids from Animal and Dairy Fats and from Vegetable Fats

Reference and Food Category Fat Intake (g/day) Trans-Fatty Acids Conc. (%) a Intake (g/day) Avg Max Avg Max

Brisson (1981) b
Butter 12.3 1.8 4.0 0.22 0.49
Milk 11.8 1.8 4.0 0.22 0.47
Meat (beef) 23.5 0.5 0.5 0.12 0.12
Total animal and dairy fats 0.56 1.08
Margarine 15.5 22.4 47.8 3.49 7.41
Shortening and oils 23.0 20.0 37.3 4.60 8.58
Salad oil 10.0 4.5 4.6 0.45 0.46
Total vegetable fats 8.54 16.45
Total dietary trans-fatty acids 9.10 17.53
Senti (1985)
Butter 5.1 3.4 0.17
Milk products 10.3 3.4 0.62
Meat + edible fat (beef) 18.1 5.8 1.42
Total animal and dairy fats 2.21
Margarine, hard 6.37 23.9 1.52
Soft 2.59 16.2 0.42
Shortening and oils 18.3 16.3 2.98
Salad oil 30.8 10.0 3.00
Total vegetable fats 8.00
Total dietary trans-fatty acids 10.21 (8.3) c
Hunter and Applewhite (1986)
Total animal and dairy fats 1.33
Margarine 2.73
Shortening and oils 10–17 0.60
Salad oil 10 0.35
Food service fats and oils 1.54
Industrial fats and oils 1.00
Total vegetable fats 6.22
Total dietary trans-fatty acids 7.55
Enig et al. (1990a)
Butter 5.0 3.1 0.15
Dairy 20.0 3.1 0.62
Meat (beef) 32.0 3.0 0.26
Edible tallow 2.2 3.0 0.07
Lard 2.9 0.4 0.01
Total animal and dairy fats 1.11
Margarine 10.2 23.0 2.35
Shortening 26.5 25.3 6.70
Salad oil 26.2 10.2 2.67
Total vegetable fats 11.72
Total dietary trans-fatty acids 12.83

the ISEOs, the National Association of Margarine Manufacturers, and A. C. Nielsen Company, and

included a 50% wastage factor for deep-frying fat. Thus, estimates of trans-fatty acid intake using

disappearance data range from 7.6 g/day estimated by Hunter and Applewhite (1986) to 12.8 g/day

estimated by Enig et al. (1990a). The experimental diets used in the study by Craig-Schmidt et al. (1984) also defi ne the relative

contribution of biohydrogenation to possible total dietary trans-fatty acid consumption. The diets

for one experimental period (nonhydrogenated; NH) were made with sources of fat such as but

ter, corn oil, and lard that had not been subjected to commercial hydrogenation. The diets for the

other period were identical to the rst but contained hydrogenated (H) products such as margarine,

hydrogenated soybean oil, and shortening. The trans-fatty acid content of the diets in the NH period

average 0.86 g/day (0.64–1.17 g/day) and 1.0% of total fatty acids (0.73%–1.3%). These values

would be an estimate of the trans-fatty acids appearing in the diet as a result of biohydrogenation

in ruminants; that is, the contribution that meat and dairy products would make. The difference

between the H and NH diets would then be an estimate of the amount of trans-fatty acids in the diet

due to commercial hydrogenation. The amount of trans-fatty
acids from margarines, shortenings, and hydrogenated soybean oil ranged from 6.6% to 16% of total fatty acids (average 10.8%) and from 5.74 to 12.72 g/day (average 8.86 g/day). Using these values, the average contribution of total dietary trans-fatty acids due to commercial hydrogenation would be 91%, with only amounts contributed by meat and animal products. This value is in agreement with Emken (1984), who assumed that 90%-95% of the isomeric fat in the adipose tissue is contributed by hydrogenated soybean oil and the rest by butter fat. Using the consumption data as summarized in Table 15.17, values for the contribution of meat and dairy products to total trans-fatty acid intake ranged from 6% (Brisson, 1981) to 22% (Senti, 1985). Heckers et al. (1979) estimated that in West Germany approximately 35%-45% of the 4.5–6.4 g per capita per day trans-fatty acid consumption was due to ruminant products. This estimate is high, however, owing to the relatively low consumption of hydrogenated vegetable fat and not to an abnormally high consumption of dairy products.

E. CONSUMPTION OF POSITIONAL ISOMERS

Almost all the estimates of isomeric fatty acid consumption are for the trans-isomers only. Emken (1984), however, used analyses of hydrogenated oil samples and figures for total fat consumption to

<table>
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<tr>
<th>Reference and Food Category Fat Intake (g/day)</th>
<th>Trans-Fatty Acids Conc. (%)</th>
<th>Intake (g/day) Avg</th>
<th>Max</th>
<th>Avg</th>
<th>Max</th>
</tr>
</thead>
</table>

(Continued)
Craig-Schmidt et al. (1984) d

Total animal and dairy fats 1.00 1.30 0.86 1.17
Total vegetable fats 10.81 15.81 8.86 12.72
Total dietary trans-fatty acids 11.81 17.11 9.72 13.89

a Typical concentration (%) of trans-fatty acids in food category listed in first column.
b Calculated for Canada.
c Value that takes into account a wastage factor for frying oils and separable fat of beef retail cuts.
d Values of Craig-Schmidt et al. (1984) were based on laboratory analysis of experimental diets designed to be adequate for lactating women; all other estimates were based on disappearance data.

calculate a daily average intake of individual cis- and trans-positional monounsaturated isomers.

The value for total isomer daily consumption minus oleic acid (18:1Δ9c) is estimated to be 9.0 g,

with 2.2 g of this consisting of positional cis-isomers. Estimated values for the consumption of cis/trans-isomers containing double bonds ranging from position 6 to position 14 are shown in Figure 15.4.

VI. CONCLUDING PERSPECTIVE

This chapter has summarized available information on the isomeric fatty acid content (primarily 18:1t) of various food items and has reviewed estimates of per capita daily intake of these fatty acids from a methodological standpoint. To be useful, these data must be put into context. First, the food composition data must be put into the context of the fat content of the food and

overall fatty acid composition. Data on isomeric fatty acid composition should be reported along with the fat content of the food and expressed in grams per 100 g of food. It is crucial to consider the other fatty acids in the food as well. Adequate essential fatty acids (e.g., linoleic, 18:2\(\Delta9c, 12c\)) must be provided in the diet to minimize possible deleterious effects of isomeric fatty acids. Ackman and Mag (1998) have reviewed the potential for having less trans-fat in commercial products. Second, the desire to increase linoleic acid in the diet must also be balanced against the tendency of polyunsaturated fatty acids to become rancid. When this occurs, the consumer gets a product that is lower not only in organoleptic properties but also in “health-promoting” properties. Third, the consumption data must be put into the context of the total diet of the consumer. The number of calories consumed, the total fat in the diet, and the percentage of calories provided by fat, 6.50 6.25 6.00 2.00 1.50 1.00 0.50 0.01 0.01 0.27 0.65 1.56 1.53 1.26 0.82 0.48 0.29 0.14 0.24 6.41 0.37 0.54 0.68 0.14 0.03 0.00 6.50 6.25 6.00 2.00 1.50 1.00 0.50 0.00 6 7 8 9 10 Double bond position

![Positional octadecenoic acid isomer (g)](image15.4)


as well as the relative proportions of saturated, monounsaturated, and polyunsaturated fat, must be taken into consideration. Fourth, the consumption data must be put into the context of studies on the physiological effects of isomeric fatty acids. The amount of dietary isomeric fat used in many human and animal experiments is greater than that normally consumed by the average person. As the possible deleterious
effects of isomeric fatty acids are assessed, it is imperative to compare the amounts of these fatty acids in experimental diets with current consumption estimates. Only then can conclusions be drawn about the safety of hydrogenated fat in the diet. Finally, realization of the detrimental health effects of trans-fatty acids has prompted a move worldwide to eliminate industriously produced trans-fatty acids from the food supply. Denmark has been successful in doing this by regulating the amount of industrially produced trans-fat allowed in a food item (Astrup, 2006). In an alternate approach, enactment of legislation requiring trans-fat values on food labels has brought about rapid changes in the food supply of the United States as industry has responded to consumer pressure. Thus, the trans-fatty acid content of the diet may soon be dependent only on the amount of ruminant items it contains.

ACKNOWLEDGMENTS

We wish to thank Julie Taylor Baker, Hso-Chi Chaung, and Janet Johnson for their assistance in items.


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