Technical



Identification of Radiolytic Compounds from Beef

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ABSTRACT

Several previous papers have dealt with the formation of radiolysis products in fats, triglycerides and fatty acids. Size excusion chromatography now provides a means of separating larger, less volatile compounds, and its application to irradiated beef has resulted in a nearly complete analysis of the radiolytic products formed. The components have been identified by gas chromatography/mass spectrometry (GC/MS).

INTRODUCTION

Much of the knowledge regarding the radiation chemistry of fats is based on the study of model systems. Such systems have included free fatty acids (1,2), methyl esters (3,4), and triglycerides (4-8) having alkyl chains ranging from C₃ to C₁₈. The radiolytic products derived from these systems have been shown to be similar, and a mechanism has been postulated to explain their formation (3).

Several of the radiolytic products observed in the studies of the model systems are low molecular weight volatile carbonyl compounds and series of saturated and unsaturated hydrocarbons (6,8). Prior studies of irradiated natural fats (9) and of irradiated beef (10) have also demonstrated the presence of similar radiolytic compounds. Some of the higher molecular weight compounds which include the glyceryl residues and various recombination products have been relatively easy to separate and identify in the model systems of relatively low molecular weight such as tricaproin and tributyrin (6-8). Isolation and identification of such compounds have not been possible from higher molecular weight triglycerides or from natural systems such as meat due to the limitations of the analytical techniques available.

Recently in the work on irradiated model systems (11), several higher molecular weight radiolytic compounds have been identified, and certain recombination products have been shown to be formed which have not been reported previously. This study was undertaken to ascertain the formation of such compounds in irradiated beef.

EXPERIMENTAL PROCEDURES

A choice top round beef was obtained from a commercial source (Kansas City Beef, Framingham, Massachusetts) and was kept frozen prior to irradiation treatment. Uniform samples of beef were divided into two portions representing the control and treatment. The samples were irradiated at 50 Mrads with gamma rays (Co^{60} -1.28 x 10⁵ rads/min) in air at 25 C and kept at 5 C until analyzed.

Extraction of the lipid was carried out with chloroform/ methanol according to Bligh and Dyer (12). The methanol layer was discarded and the chloroform fraction was evaporated under nitrogen to a convenient volume. The lipid extract was passed through a silicic acid column to effect removal of phospholipids from the nonpolar lipids.

The analysis of free fatty acids was carried out on 10 g of extracted beef fat containing dodecanoic acid as an internal standard. The extract was passed through the KOH/Silicic acid column (13) to separate the free fatty acids. Subsequently, the free fatty acids eluate was analyzed by a Carbowax 20 M (FFAP) column.

Fractionation of the radiolysis products was carried out by means of size exclusion chromatography and analysis performed by gas chromatography/mass spectrometry (GC/MS) as described in a previous publication (11). In this work gas chromatographic analysis of the fractions was performed using the following five stationary phases: Carbowax 20 M, Dexil-300, Carbowax 20 M (FFAP), and SF-96.

Authentic compounds such as ketones, lactones, and triglycerides were purchased from several commercial sources. Long chain gamma lactones were obtained through the courtesy of Dr. J.S. Showell of Eastern Regional Research Lab and Dr. M.J. Diamond of Western Regional Research Lab, U.S. Dept. of Agriculture. Palmitone (16-hentriacontanone) and pentadecyl heptadecenyl ketone (16-tritriaconta-24-enone) were synthesized by the method of Gil-

TABLE I

Quantitative Analysis of the Major Free Fatty Acids Produced in Beef Irradiated at 50 Mrads at 25 C^a

| | Beef | Irradiated beef | Increase due to irradiation |
|------------------|-------------|--------------------|-----------------------------------|
| Free fatty acids | mg/10 g fat | mg/10 g fat | mg/10 g fat |
| Myristic acid | 14.5 | 27,1 | 12.5 |
| Palmitic acid | 69.9 | 134.3 | 64.3 |
| Palmitoleic acid | 14.1 | 22.9 | 8.8 |
| Stearic acid | 31.0 | 66.5 | 35.4 |
| Oleic acid | 83.6 | 146.6 | 63.0 |
| Total | 213.2b | 397,4 | 184.0 |

^aAverage of 16 determinations.

^bThe background amount of free fatty acid in these samples is relatively high. The values have been corroborated by direct gc analysis of the fat extract on FFAP/Carbowax. Apparently some degree of lipolysis had occurred before irradiation.

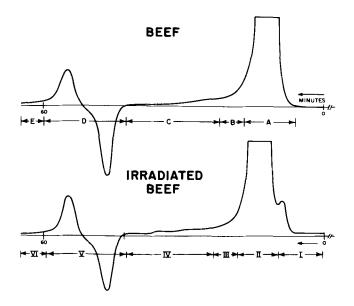


FIG. 1. Gel permeation chromatography of fat extracts. Column: 16' x 3/8" poragel $60^{\circ}A + 8'x3/8"$ poragel $100^{\circ}A$. Solvent: Chloroform. Flow rate: 2 ml/min. at 800 psi. RI attenuation: 64X. Sample size; 2ml. Concentration: 50/50; wt/vol.

man and Nelson (14). Propanediol diesters were synthesized by using 1,2-propanediol and 1,3-propanediol and the appropriate acid chloride in solution of chloroform and pyridine following Baumann's procedure (15).

RESULTS AND DISCUSSION

In this study, the chromatographic analysis of free fatty acids in beef and irradiated beef showed an increase in all the free fatty acids in the irradiated samples. For comparative purposes, only the major free fatty acids were quantitized. Table I presents the quantitative analysis of five major free fatty acids in beef and irradiated beef.

The size exclusion chromatograms of the control and irradiated samples are presented in Figure 1. Five continuous fractions (A-E) were collected from each eluate of the control sample and pooled to obtain adequate concentration of lipid components within each designated fraction. Similarly, five fractions (II-VI) from the eluate of the irradiated sample were collected at intervals similar to those of the control sample. Due to the appearance of a shoulder on the triglyceride peak representing compounds of greater apparent size (Fig. 1), an additional fraction (Fraction I) was collected from the irradiated samples. The fractions collected were evaporated under nitrogen and analyzed by GC/MS.

Gas chromatographic analyses of these fractions were made on various columns. Two representative gas chromatograms (Figures 2 & 3) showing most of the radiolytic compounds are presented here. In most cases unequivocal identification of the radiolytic compounds was made by comparing their GC retention times and mass spectra with those of the corresponding authentic compounds. In a few cases where authentic compounds were not available. identification was based on the interpolation of retention time among the retention times of other members of the same homologous series and by comparison of the mass spectrum with the mass spectra of appropriate homologs. Table II presents a list of the radiolytic compounds identified in this study. No radiolytic compounds were identified from the corresponding fractions in the sample of unirradiated beef. These compounds include series of saturated and unsaturated hydrocarbons, aldehydes, alcohols, alkyl esters, fatty acids, lactones, ketones, and diol esters. The compounds without peak numbers correspond to those identified on gas chromatographic columns for which chromatograms are not shown here.

On the whole, the radiolytic compounds found in this study are consistent with those expected from consideration of the mechanisms and deduced from the prior studies of model systems. Many of the compounds found, however, have not actually been identified or reported previously in irradiated beef. The newly found compounds are distinguished by superscript^a in Table II.

The compounds identified in Fraction IV (Fig. 2) are members of the series of classes corresponding to acyl and acyloxy cleavage of the aliphatic side chains of the triglycerides. The compounds in Fraction III (Fig. 3) represent the larger and less volatile radiolytic products such as the diol diesters and certain recombination products which constitute peaks 24-32 on this chromatogram. In this study and in previously reported work on model systems (11), several lactones were identified whose presence and possible route of formation will be published in a separate paper.

The corresponding fraction (B) from the control sample contained cholesterol and related compounds identified as cholestatriene, dehydrocholesterol, and cholestadiene-7one. These compounds were also present in the irradiated sample. Since they are nonradiolytic in nature and were originally present in the sample, they are classified under miscellaneous in Table II.

GC analysis of Fraction II, corresponding to triglycerides, was made on a 2 ft SE-30 colum at high temperature and flow rate. The gas chromatogram of this fraction was similar to that of the corresponding Fraction A from unirradiated beef. Due to the high flow rate of the carrier gas, mass spectra of the components in these fractions could not be obtained.

It has been postulated from previous studies of model systems and natural products that the predominant free radicals produced as a result of radiolysis in beef fat are alkyl radicals such as pentadecanoyl and 9:10 heptadecanoyl. Consequently, long chain hydrocarbons, ketones and diketones are expected to be formed predominantly as recombination products of the above radicals. In this study two such recombination products were identified. These were palmitone and 16-tritriaconta-24-enone as expected from the relative abundance of the alkyl moities in beef fat. The amounts of the ketones are small compared to those of the primary radiolytic compounds.

The analysis of propanediol diesters revealed a greater abundance of 1,2-propanediol diesters than the corresponding 1,3-configurations. This is consistent with the higher probability of cleavage at the primary position.

The appearance of a peak before triglycerides on the size exclusion chromatogram (labeled as Fraction I in Fig. 1) suggests the presence of radiolytic compounds of high molecular weights. On the basis of the detector response, the components in Fraction I are estimated to be present in a greater quantity than other radiolytic compounds. This fraction was found to be very viscous after evaporation of the solvent. Because of its low volatility, this fraction could not be separated by gas chromatography. Further study of this fraction is needed to establish the nature of these components, and techniques such as thin layer chromatography, liquid-liquid chromatography, and high resolution mass spectrometry are currently in progress to augment the already existing data to establish the full scope of the radiolytic products found in irradiated beef.

ACKNOWLEDGMENT

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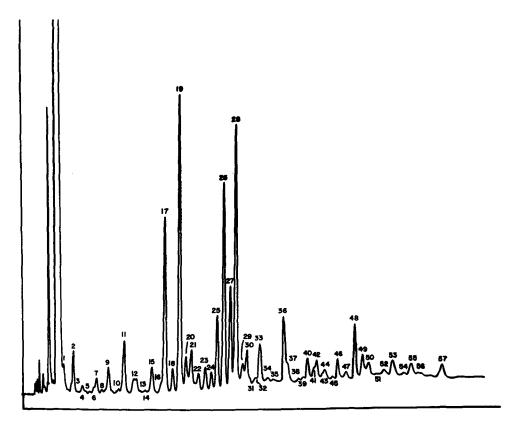


FIG. 2. Gas chromatogram of fraction IV. Column: 8'x1/8" - 15% CW20M (80/100 mesh chromosorb W). Temperature: 70-250 C (4 C/ min). Flow rate: 20 ml/min. Detector: FID. Attenuation: 64x100.

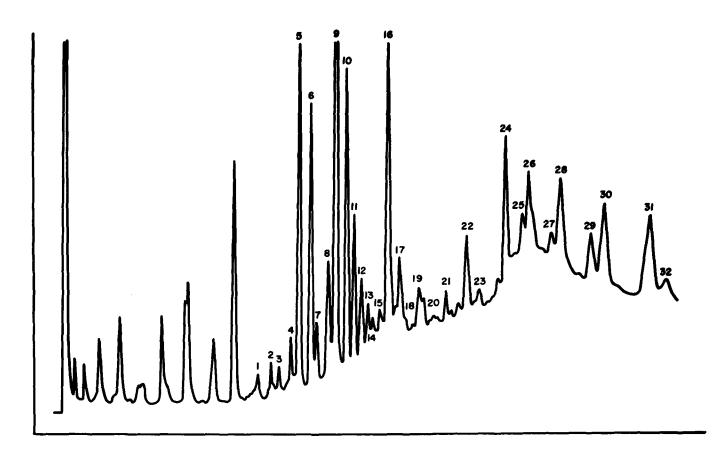


FIG. 3. Gas chromatogram of fraction III. Column: 5'x1/8"-3% OV-17 (80/100 mesh chromosorb W). Temperature: 100-340 C (8 C/min). Flow rate: 40 ml/min. Detector: FID. Attenuation: 64x100.

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| 25 A Decaonol ⁴ 31 H ^C Hexadecanoic acid 1,2-hexadecanoyl propanediol diesters 29 Tridecanol ³ 43 H ^C Heptadecanoic acid Tridecanol ³ 43 H ^C Octadecanoyl, octadecenoyl 1,2-propanediol diesters 30 Tetradecanol ³ 43 H ^C Octadecanoyl, octadecenoyl 1,2-propanediol diesters 30 Tetradecanol ³ 30 H ^E Cotadecanoyl, octadecenoyl 1,2-propanediol diesters 30 Dotadecenol ³ 0.0ctadecenoic acid 14 H Esters ³ 0.0ctadecenoic acid 14 H Esters ³ 1.1.1.1.tetradecanoate or isomers 31 12 Me-dotecanoate 23 A ^D 13 dipalmitin 1,2-octadecanoate 23 A ^D 1,2-octadecenoid diesters 30 Hexadecanoate 40 A ^D Miscellaneous Me-hexadecanoate 40 A ^D Me-hexadecanoate 40 A ^D Me-hexadecanoate 40 A ^D Me-hexadecanoate 51 H ^C Me-hexadecanoate 51 H ^C Me-hexadecanoate 51 H ^C Me-ortadecanoate 51 H ^C Me-ortadecenoate 51 H ^C Me-ortadecanoate 51 A ^C Me-or | Pentadecene | 21 | Ξ· | Hexanol | 13 | Hc | Hexadecanoic acid | | | Tetradecanoyl, hexadecanoyl 1, 3-propanediol diesters | | ¥ |
| 28 A Undecanol ⁴ Heptadecancic acid 1,3-hexadecanoyl propanediol diesters 29 7 Tridecanol ⁴ 43 Hc Octadecanoyl octadecanoyl 1,2-propanediol diesters 29 1 Tridecanol ⁴ 1 Heptadecanoic acid 1,3-hexadecanoyl 1,2-propanediol diesters 29 1 Tridecanol ⁴ 0 Octadecenoic acid Hexadecanoyl, octadecenoyl 1,2-propanediol diesters 30 10 A Esters ⁴ Octadecenoic acid 1,3-hexadecanoyl, octadecanoate or isomers 31 10 A Esters ³ Octadecenoic acid 1,3-hexadecanoate or isomers 31 10 A Esters ³ Octadecenoic acid 1,2-octadecanoate or isomers 31 11 H Esters ³ D 1,2-octadecanoate or isomers 31 11 H H Esters ³ D 1,2-octadecanoyl propanediol diesters 30 11 H H Esters ³ D 1,2-octadecanoate or isomers 31 11 H H Esters ³ D 1,2-octadecanoate or isomers 31 11 H | Hexadecene | 25 | A | Decaonol ^a | 31 | Нс | Hexadecenoic acid | | | 1,2-hexadecanoyl propanediol diesters | 28 | A |
| Tridecanola 43 Hc Octadecanoic acid Tetradecanoyl, octadecenoyl 1,2-propanediol diesters 29 Tridecanola 0 Hexadecanoyl, octadecenoyl 1,2-propanediol diesters 30 Hexadecanola 0 Octadecenola 31 10 A Octadecenola 31 11 H Esters 30 12 H Hexadecanoyl, octadecenoyl 1,2-propanediol diesters 30 12 Octadecenola 1,3-dipalmitin 31 13 1,2-ottadecanoyl propanediol diesters 32 ne 18 H Me-dodecanoate 23 ne 18 H Me-dodecanoate 32 ne 20 H Me-dodecanoate 23 ne 30 H Me-dodecanoate 32 ne 30 H Me-dodecenoate 40 40 ne 30 H Me-dodecenoate 40 40 ne 30 H Me-dodecenoate 45 40 ne 30 H Me-dodecenoate 45 40 | Heptadecene | 28 | A | Undecanol ^a | | | Heptadecanoic acid | | | 1,3-hexadecanoyl propanediol diesters | 29 | A |
| TetradecanolaOctadecenolaExadecanoyl 1,2-propanediol diesters30HexadecanolaHexadecanoyl, octadecanoyl 1,2-propanediol diesters3110AOctadecenola3114HEstersa3014HEstersa3114HEstersa3114HEstersa3115H1,3-dipalmitin3116A1,3-dipalmitin31171,3-dipalmitin313118H1,3-dipalmitin3118H1,3-dipalmitin3118HMe-dodecanoate23Ab18HMe-dodecanoate23Ab18HMe-dodecanoate321,3-dipalmitin19HMe-dodecanoate23Ab10AMiscellaneous321,3-dipalmitin10AMe-dodecanoate23Ab10AMe-entidecanoate2411Me-bexadecanoate51Hc11Me-ottadecanoate51Hc11Me-ottadecanoate51Hc11Me-ottadecanoate54Ab11Me-ottadecanoate54Ab11Me-ottadecanoate54Ab12Me-ottadecanoate54Ab13Me-ottadecanoate54Ab14Me-ottadecanoate54Ab15Me-ottadecanoate54Ab1 | | | | Tridecanol ^a | 43 | Нс | Octadecanoic acid | | | Tetradecanoyl, octadecenoyl 1,2-propanediol diesters | 29 | ¥ |
| Hexadecanol ⁴ Hexadecanol ⁴ 10 A 12 Octadecenol ³ 13 (Jycery1-1-tetradecanoate or isomers 31 14 H 18 H 14 H 18 H 14 H 15 (Jycery1-1-tetradecanoate or isomers 31 16 A 17 (Jycery1-1-tetradecanoate or isomers 31 18 H 19 (Jycery1-1-tetradecanoate or isomers 31 10 A 12 (Jycery1-1-tetradecanoate or isomers 31 13 (Jycery1-1-tetradecanoate or isomers 31 14 H 15 (Jycery1-1-tetradecanoate or isomers 31 16 20 18 H 19 (Jycery1-1-tetradecanoate or isomers 31 10 A 16 20 17 (Jycery1-1-tetradecanoate or isomers 31 18 H 19 Me-tetradecanoate 40 10 A 11 (Jycery1-1-tetradecanoate or isomers 31 12 H 13 (Jycery1-1-tetradecanoate 42 14 Me-tetradecanoate 43 16 A 17 Me-tetrade | Alkadienes | | | Tetradecanol ^a | | | Octadecenoic acid | | | Hexadecanoyl, octadecenoyl 1,2-propanediol diesters | 30 | A - |
| 10 A Octadecenol ⁴ 31 10 A Esters ⁴ 31 11 H H Esters ³ 31 11 H H Esters ⁴ 32 11 H H Esters ³ 32 12 H Me-dodecanoate 23 Ab 13 1,2-octadecenoyl propanediol disters 32 14 H Me-dodecanoate 34 15 Me-terradecanoate 45 H 16 20 H Me-terradecanoate 45 16 30 H Me-terradecanoate 45 16 30 H Me-terradecanoate 24 16 Me-herradecanoate 48 Ab 24 17 Me-herradecanoate 54 Ab 24 18 Me-herradecanoate 54 Ab 24 16 Me-herradecanoate 54 Ab 24 18 Me-herradecanoate 54 24 19 Me-herradecanoate 54 Ab 10 Me-herradecanoate 54 Ab 18 Me-herradecanoate 54 19 Me-herradecanoate | : | | | Hexadecanola | | | | | | Hexadecanoyl, octadecanoyl 1,2-propanediol diesters | 30 | A : |
| 10 A 14 H Esters ^a 31 12 H Me-dodecanoate 23 32 18 H Me-dodecanoate 23 32 10 A Miscellaneous 32 13 H Me-dodecanoate 23 40 10 A A Miscellaneous 32 11 Me-tetradecanoate 40 A A 11 Me-tetradecanoate 40 A A 11 Me-tetradecanoate 40 A A 11 Me-tetradecanoate 40 A A A 11 Me-tetradecanoate 45 A A A A 11 Me-tetradecanoate 48 A | Decadiene | | | Octadecenol ⁴ | | | | | | Glyceryl-1-tetradecanoate-2-octadecanoate or isomers | 31 | H |
| 14 H Esters ^a 32 ne 18 H Miscellaneous 32 ne 18 H Me-dodecanoate 23 Ab ne 22 H Me-dodecanoate 23 Ab ne 30 H Me-tetradecanoate 40 Ab 24 ne 30 H Me-tetradecanoate 45 Hc 24 ne 30 H Me-tetradecanoate 48 Ab 24 ne 30 H Me-tetradecanoate 45 Hc 24 ne 30 H Me-tetradecanoate 51 HC 24 Ne-hexadecanoate 51 HC Cholestatritiene 22 Me-octadecanoate 54 Ab Cholestadiene-7-one 25 Me-octadecanoate 54 Ab Cholestadiene-7-one 25 | Dodecadiene | 10 | A | | | | | | | 1,3-dipalmitin | 31 | A |
| 18 H 22 H Me-dodecanoate 23 Ab 26 H Me-tetradecanoate 23 Ab 26 H Me-tetradecanoate 45 Hc 30 H Me-pentadecanoate 45 Hc 24 30 H Me-pentadecanoate 45 Hc 24 Me-hexadecanoate 48 Ab Dehydrocholesterol 24 Me-hexadecanoate 48 Ab Cholestatriene 24 Me-heptadecanoate 51 Hc 24 24 Me-ortadecanoate 54 Ab 24 24 Me-ortadecanoate 54 Ab 24 24 Me-ortadecanoate 54 Ab 25 24 Me-ortadecanoate 54 Ab 25 26 Me-ortadecanoate 54 Ab 25 26 Me-ortadecanoate 54 Ab 26 26 Me-ortadecanoate 54 Ab 26 26 Me-ortadecanoate 54 26 </td <td>Tridecadiene</td> <td>14</td> <td>H</td> <td>Esters^a</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>1,2-octadecenoyl propanediol diesters</td> <td>32</td> <td>A</td> | Tridecadiene | 14 | H | Esters ^a | | | | | | 1,2-octadecenoyl propanediol diesters | 32 | A |
| 22 H Me-dodecanoate 23 A ^D 26 H Me-terradecanoate 40 A ^D 30 H Me-pentadecanoate 40 A ^D Me-hexadecanoate 48 A ^D Me-hexadecenoate 48 A ^D Me-hexadecenoate 48 A ^D Me-octadecanoate 51 H ^C Me-octadecanoate 51 H ^C Me-octadecenoate 54 A ^D Me-octadecenoate 54 A ^D | Tetradecadiene | 18 | н | | | | | | | | | |
| 26 H Me-tetradecanoate 40 Ab 30 H Me-pentadecanoate 45 H ^c Cholesterol Me-hexadecanoate 48 Ab Me-hexadecanoate 48 Ab Me-octadecanoate 51 H ^c Me-octadecanoate 54 Ab Me-octadecanoate 54 Ab | Pentadecadiene | 22 | Н | Me-dodecanoate | 23 | Чb | | | | Miscellaneous | | |
| 30 H Me-pentadecanoate 45 H ^c 24 Me-hexadecanoate 48 A ^b Dehydrocholesterol 24 Me-hexadecanoate 48 A ^b 24 Me-hexadecanoate 51 H ^c 22 Me-octadecanoate 51 H ^c 23 Me-octadecanoate 54 A ^b 23 | Hexadecadiene | 26 | н | Me-tetradecanoate | | $^{\rm Ab}$ | | | | | | |
| 48 Ab Dehydrocholesterol 24 48 Ab Cholestatriene 22 49 Cholestatiene 22 54 Ab 25 | Heptadecadiene | 30 | Н | Me-pentadecanoat | | Нс | | | | Cholesterol | 24 | A |
| e 51 H ^c Cholestatriene 22 54 A ^b Cholestadiene-7-one 25 | | | | Me-hexadecanoate | | ЧÞ | | | | Dehydrocholesterol | 24 | Η |
| e 51 H ^c Cholestadiene-7-one 25 54 A ^b | | | | Me-hexadecenoate | | | | | | Cholestatriene | 22 | H |
| 54 Ab | | | | Me-heptadecanoat | | нс | | | | Cholestadiene-7-one | 25 | A |
| Me-octadecenoate | | | | Me-octadecanoate | | qΡ | | | | | | |
| | | | | Me-octadecenoate | | | | | | | | |

TABLE II Radiolytic Compounds Identified from Beef

> ^aCompounds not identified in previous work. ^bGC/MS identification based on authentic compounds. ^cGC/MS identification based on homologous series and literature.

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REFERENCES

- 1. Sheppard, C.W., and V.L. Barton, J. Am. Chem. Soc. 68:1636 (1964).
- Howton, D.R., and G. Wu. Ibid. 89:516 (1967).
- 3. Nawar, W.W., Progress Chem. Fats Other Lipids Part 2, 13:91 (1972). 4. Merritt, C. Jr., P. Angelini, M.L. Bazinet, and J.J. McAdoo,
- Adv. Chem. Ser. 56:225 (1966).
- Dubravcic, M.J., and W.W. Nawar. JAOCS 4:655 (1968).
 LeTellier, P.R., and W.W. Nawar, J. Agric. Food Chem. 20:129 (1972).
- 7. LeTellier, P.R., and W.W. Nawar, JAOCS 49:259 (1972).
- 8. Meidani, J., W.W. Nawar, W.G. Yeomans, and C. Merritt, Jr.,

JAOCS 54:496 (1977).

- 9. Champagne, J.R., and W.W. Nawar, J. Food Sci. 34:335 (1969). 10. Merritt, C. Jr., Radiation Res. Rev. 3:353 (1972).
- 11. Vajdi, M., W.W. Nawar, and C. Merritt, Jr., JAOCS 55:849 (1978). 12. Bligh, E.B., and W.J. Dyer, C.J. Biochem. Physiol. 37(8):911
- (1959).
- McCarthy, R.D., and A.H. Duthie, J. Lipid Res. 3:117 (1962). 13.
- Gilman, H., and J.F. Nelson, Rec. Trav. Chem. 55:518 (1936).
 Baumann, W.J., H.H.O. Schmid, H.W. Ulshaffer, and M.R. Mangold, Biochim. Biophys. Acta. 144:335 (1967).

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