Low Calorie Lipids

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To effect the calorie intake significantly, the fats or fatty foods consumed should supply no more than 4 to 5 kcal of available energy per g. The importance of functional requirements and metabolic considerations, *e.g.*, heat of combustion, absorptivity, digestibility, and nontoxicity of metabolites is described. Reference is made to marketed products based on dilution of regular fats with water and/or air, and to potential fat-like products by the synthetic chemical approach. The cost involved to prove safety of new products is identified as the major hurdle.

Lipids are a heterogeneous class of substances, usually insoluble or poorly soluble in water. The lipids of our diet are known as fats or oils, dependent upon their physical state at room temperature. Phospholipids, sphingolipids, and steroids are physiologically very important but, chemically and functionally, quite different from the triglycerides which make up the fats and oils of our diet.

Dietary fats represent approximately 40 to 45% of our daily caloric intake (Battelle, 1964; Goldsmith, 1965) and, compared to Denmark or England, we eat significantly more fat, although the daily food consumption in total calories is about the same (Table I). Not only are we eating more fat, but we seem to enjoy it more also when compared to prior generations. [From 1936 to 1955 the amount of fat consumed as percent of total caloric intake grew steadily from 38 to 44%, although, surprisingly enough, the total energy intake has actually decreased somewhat over several generations (Rice, 1967)].

Why are we concerned with the fat in our diet when we believe, at least until recently, that our diet has been consistent with the attainment of one of the best health patterns in the world (Nat. Acad. Sci., 1962)?

Obesity has been correlated statistically with vascular diseases and diabetes, and, generally with a shortened life expectancy. Whether obesity is a main cause of arteriosclerosis or plays only a supporting role in its pathogenesis is still uncertain (Kaunitz, 1966). Some investigators have implicated dietary fats as factors in elevated levels of plasma cholesterol and have suggested that we should reduce the consumption of fats.

Assuming that a diet containing 25% of the calories as fat is the lowest reasonable value, and that the protein needs of the body require a contribution of 10 to 12% of the calories, Table I illustrates the calculated values of fat and protein for a daily intake of 2600 cal as recommended by Nat. Acad. Sci. (1968).

The metabolically available energy of fats is usually about 9.0 kcal per g, which is more than twice that of proteins or carbohydrates (4.0 kcal per g). Only about a third of the dietary energy supplied by fat comes from butter, margarine, shortening, cooking oils, or salad oils. The other two-thirds are associated with natural food products such as meat, dairy products (cheese, milk), eggs, nuts (Nat. Acad. Sci., 1962; Stiebeling, 1958).

The significance of this observation seems to be that a novel low-caloric fat product would have to show an available caloric value between 4 and 5 kcal per g or less in order to affect the total caloric intake by the consumer by at least 10% per day (Table II). This, therefore, constitutes a minimum requirement for a low-caloric fat product.

Other requirements are more obvious. The product must be functionally analogous to the fat it substitutes; it must be nontoxic and its metabolites, if not identical with those that occur naturally in the body, must be completely excreted.

The most critical factors which influence the ultimate energy value of a given fat product ingested are the heat of combustion, the coefficient of digestibility, and the degree of utilization in the body. The heat of combustion of fats is influenced by the ratio of hydrogen to oxygen. The lower this ratio, the lower the heat of combustion. Hence, glycerides of short-chain fatty acids exhibit a somewhat lower kcal per g value than glycerides of long-chain fatty acids (Table III).

The heat of combustion of any matter is a physical characteristic which, in the case of fats, is proportional to the ratio of hydrogen to oxygen. The lower this ratio, the lower the heat of combustion. Glycerides of short-chain fatty acid will exhibit a somewhat lower available calorie-per-gram value than glycerides of long-chain fatty acids (Table III).

If the term "coefficient of digestibility" measures the difference between the amount of food (fat) ingested and the amount excreted in the feces, it appears that the digestibility of fat increases with the degree of saturation and the length of the carbon chain (Mattil, 1946; Carroll, 1958). This statement oversimplifies a complex and varied process, which includes emulsification, partial hydrolysis, absorption, and transport of what was initially a triglyceride to the liver (Tidwell, 1958) (Table IV).

Naturally-occurring fats and oils may have a coefficient of digestibility of 95% or above (Frazer, 1958).

Thus, there are only two principal routes to low-caloric fats: The dilution of an existing fat with a noncaloric, functionally compatible entity which results in a "fat-like"

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Table I. Average Food Consumption per Person/per Day

Country	Total Calories	Protein g	Protein cal	Protein %	Fat g	Fat cal	Fat %
Denmark[a]	3255	88	352	11	139	1251	38
England[a]	3200	85	340	11	128	1150	36
U.S.A.[a]	3220	97	388	12	149	1341	42
Recommended[b] for 35–55 yr male (1968)	2600	65	260	10	72	650	25

[a] See Battelle (1964). [b] From Nat. Acad. Sci. (1968) and calculated for limits suggested in Nat. Acad. Sci. (1962).

Table II. Contribution of Low Caloric Fat Product (4.5 cal/gal) in a Typical Diet

	Standard	Reduced
Visible fat (cal)	447	220
Total fat (cal)	1341	1121
Total caloric intake/per person/per day (cal)	3220[a]	3000
Total caloric reduction		7%

[a] See Table I.

Table III. Heats of Combustion of Fatty Acids

Acid	Number of carbons	Hydrogen/ oxygen ratio	Heat of combustion, cal/g
Acetic	2	2	3.49
Propionic	3	3	4.96
Butyric	4	4	5.95
Caproic	6	6	7.16
Palmitic	16	16	9.36
Oleic	18	17	9.41
Stearic	18	18	9.54

Table IV. Coefficients of Digestibility of Fatty Acids and Glycerides[a]

Acids	Number of carbons	Percent
Butyric	4	100
Caproic	6	100
Caprylic	8	100
Capric	10	100
Lauric	12	86
Myristic	14	64
Palmitic	16	39
Stearic	18	23
Oleic	18[b]	84
Behenic	22	7
Erucic	22[b]	51
Triglyceride		
Triolein		90
Trilinolein		97
Trierucin		63
Tripalmitin		22

[a] Taken from Carroll (1958). Permission for reprinting granted from Editor, *J. Nutr.* [b] Acid contains one double bond.

material, having a lower available energy value per g than the fat it contains; and the synthetic-chemical approach which creates fat-functional and fat-like materials which exhibit a lower caloric value because of their structural design.

There are many commercial products which are based on the first approach where the noncaloric diluent is water, *e.g.*, spreadable, low-caloric, edible fats resembling butter and margarine produced by forming solidified water-in-oil emulsions. The water phase may represent 50% of the emulsion and usually contains a thickener (CM cellulose, gelatin, alginic esters). In the fat phase an emulsifier is present (*e.g.*, lecithin, sorbitol esters, mono- or diglycerides, etc.) (Battelle, 1964; Berndt and Krett, 1959; Carter Products, 1965; Dublin and Marks, 1952; Frazer, 1958; Goldsmith, 1965; Graves, 1967; Kuhrt and Broxholm, 1968; Mickle, 1964; Nat. Acad. Sci., 1962; Peebles and Girvin, 1952; Pinkalla *et al.*, 1965; Rice, 1967; Unilever, 1964, 1965, 1966, 1967).

Another system related to the above principle is low-caloric spreads based on fat-in-water emulsions. The aqueous phase may contain 7–8% of protein; the fatty phase usually consists of an emulsion of vegetable oils with flavor and vitamins which is dispersed in the aqueous phase, cooled, and mechanically treated to yield the spread (Mattil, 1946; Carroll, 1958; Stiebeling, 1958; Tidwell, 1958; Booth, 1961, 1963; Kaunitz, 1961, 1966).

Among the synthetic dietary fats is a type of fat which is based on an average fatty acid chain between 8 and 10 carbons (Drew, 1964, 1965). This material (MCT—medium-chain triglycerides) shows a somewhat lower caloric value, 8.3 kcal/g (Isselbacher, 1964; Holt, 1964; Hashim, 1964), but, more significantly, it offers other therapeutic benefits which become useful in the nutritional management of subjects with impaired fat digestion or absorption (Pinter, 1964; Holt *et al.*, 1965).

Another class of new-type synthetic fats are amylose esters (Gros and Fenge, 1962) and the diglyceride esters of short-chain dibasic acids (fumaric, succinic, adipic) (Fenge and Ward, 1958, 1960; Ward *et al.*, 1959). Amylose stearate, amylose palmitate, amylose oleate, distearin adipate, and glycerol adipate showed a low digestibility and poor utilization whereas diolein fumarate was well digested but poorly utilized (Booth and Gros, 1963).

A structurally interesting group of fat-substitute compositions are esters of neopentyl-type alcohols (pentaerythritol, etc.) esterified with fatty acids. They are nontoxic and are not digested like normal fats (Minich, 1960).

Finally, there exists a vast group of fat-like materials which have been developed originally to be used as emulsifying agents for food use. A typical material is polyoxyethylene stearate (Nat. Acad. Sci., 1958) which has been extensively tested; its toxicology and safety have been studied as an emulsifying agent. Although the average coefficient of digestibility is about 80%, its caloric contribution is only 4.2 kcal/g. Its caloric contribution depends almost entirely on the stearate moiety, the bulk of the polyoxyethylenediol part of the molecule is excreted unchanged within 24 hr.

Thus, from a chemist's point of view, it appears as if a broad spectrum of functionally compatible alternatives to the natural fats have been produced, but in order to develop the needed data required to prove safety, an effort comparable to that needed for the acceptance of a new drug is necessary and is made more difficult by the relatively high concentrations which have to be studied, to justify its use as a food ingredient.

LITERATURE CITED

Battelle Tech. Rev. **13**(6), 4 (1964).
Berndt, L., Krett, O. (to Nat. Dairy Prod. Corp.) U.S. 3,010,830, Appl. September 2, 1959.
Booth, A., *J. Amer. Oil Chem. Soc.* **38,** 84–6 (1961).
Booth, A., Gros, A. T., *J. Amer. Oil Chem. Soc.* **40**(10), 551–3 (1963).
Carroll, K. K., *J. Nutr.* **64,** 339–410 (1958).
Carroll, K. K., Richards, J. F., *J. Nutr.* **64,** 411–24 (1958).
Carter Products, Inc., Neth. Appl. 6,504,564, October 11, 1965.
Drew Chem. Corp., Belg. 645,202, September 14, 1964.
Drew Chem. Corp., Neth. Appl. 302,869, October 25, 1965.
Dublin, L. I., Marks, H. H., Recording and Statistical Corp. Press, New York (1952).
Fenge, R. O., Ward, T. L., *J. Amer. Chem. Soc.* **80,** 6338–41 (1958).
Fenge, R. O., Ward, T. L., *J. Amer. Oil Chem. Soc.* **37,** 291–4 (1960).
Frazer, A. C., *Brit. Med. Bull.* **14,** 212–20 (1958).
Goldsmith, G. A., Presented at the Conf. Adv. Food Processing, March 22, 23, 24 (1965).
Graves, R. (to Graves-Stambaugh Corp.) U.S. 3,314,798, April 18, 1967.
Gros, A. T., Fenge, R. O., *J. Amer. Oil Chem. Soc.* **39,** 19–24 (1962).
Hashim, S. A., *New Engl. J. Med.* **270,** 756–61 (1964).
Holt, P. R., *Pediatrics* **34,** 629–35 (1964).
Holt, P. R., Hashim, S. A., Van Itallie, T. B., *Amer. J. Gastroenterol.* **43,** 549–59 (1965).
Isselbacher, K. I., *Medicine* **43,** 347–61 (1964).
Kaunitz, H., *Nature* (London) **192,** 9 (1961).
Kaunitz, H., *J. Amer. Oil Chem. Soc.* **43,** 175 (1966).
Karasch, M. S., Nat. Bur. Std. (U.S.) Research **2,** 359 (1929).
Kuhrt, N., Broxholm, R. (to Eastman Kodak Co.) U.S. 3,388,999, June 18, 1968.
Mattil, K., *Oil Soap* **23,** 344–7 (1946).
Mickle, J., *Food Technol.* **18,** 1483–5 (1964).
Minich, A. (to Heyden-Newport Chem. Corp.), U.S. 2,962,419 Nov. 29, 1960.
Nat. Acad. Sci., Nat. Res. Council, Publ. 646 (1958).
Nat. Acad. Sci., Nat. Res. Council, Publ. 575 (1962).
Nat. Acad. Sci., Nat. Res. Council, Publ. 1694 (1968).
Peebles, D., Girvin, M. (to Western Condensing Co.), U.S. 2,622,-984, Dec. 23, 1952.
Pinkalla, H. A., Neuser, G. L., Cook, L. R., Korfhage, R. F. (to W. R. Grace and Co.) U.S. 3,223,532, December 14, 1965.
Pinter, K. G., *Amer. J. Clin. Nutr.* **15,** 293–8 (1964).
Rice, E. E., *Ann. Food Technol. Conf.* (1967).
Stiebeling, H. K., *Fed. Proc.* **17,** 770 (1958).
Tidwell, H., *Proc. Soc. Exp. Biol. Med.* **98,** 12–16 (1958).
Unilever, N. V., Neth. Appl. 6,515,919, June 9, 1967.
Unilever, N. V., Neth. Appl. 6,403,486, October 6, 1964.
Unilever, N. V., Belg. 656,949, June 10, 1965.
Unilever, N. V., Neth. Appl., 6,604,239, July 25, 1966.
Ward, T. L., Gros, A. T., Fenge, R. O., *J. Amer. Oil Chem. Soc.* **36,** 667–71 (1959).

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