Other treatments of vegetable oils to give polymerizable materials should be mentioned. Hydroxylation, usually by blowing with air, followed by dehydroxylation in the presence of dehydrating agents is employed on linseed and soybean oils (28). Physical processes, such as solvent segregation, are also employed. One type (29) depends on the well known solubility difference of similar molecular species having different molecular weights. In this process the oil is first partially heat-bodied, then extracted with acetone or similar solvents to remove the unpolymerized portion. Since this portion contains the more saturated and less reactive components, the remainder is a harder-drying and faster-polymerizing material.

A more recent development is the liquefied hydrocarbon (propane, etc.) method wherein the solvency is apparently specific for a given degree of unsaturation; this makes possible the segregation of fatty oils into unsaponifiable, low iodine value, and higher iodine value fractions without affecting the chemical constitution of any of the parts.

Experimental

Viscosity-Iodine Value Relationship for the Polymerization of Linseed Oil With and Without Catalysts: 3,500 gm. of alkali refined linseed oil was polymerized at 590° F. (310° C.) to a Gardner-Holdt viscosity of Z-5 (98.5 poises) in a 1½-gallon stainless steel kettle. Samples were withdrawn at intervals and the viscosity and iodine value determined. Data is recorded in the accompanying table, Column A. 3,500 gm. of commercial fast-bodying oil "B" (Column B) and 3,500 gm. of commercial fast-bodying oil "C" (Column C) were polymerized and examined in the same manner.

Inhibition of the Polymerization of Styrene by Drying-Oil Polymerization Catalysts: 20-ml. samples of styrene monomer (from which the inhibitor had been removed by careful washing with 10% aqueous KOH and water) were placed in glass ampoules. To one was added 0.1% hydroquinone, to the second 0.1% β-methyl anthraquinone, and to the third 0.1% diphenol carboxyl anthracene; to a fourth (Control) no inhibitor was added. All four tubes were immediately sealed off and placed in a 60° C. bath for 2 hours. They were permitted to stand in the sunlight at room temperature for four weeks.

At the end of this period the control was very viscous, so that several minutes were required to note any flow when the ampoule was held at 90° to the vertical. The three tubes containing additives were apparently little polymerized, all three being very limpid.

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The Digestibility of Fats — A Correlation of Experimental Data*

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THE digestibility of fats has been studied extensively in a number of laboratories over the past 30 years, the major portion of the data having been collected by several groups of workers, each of which used some one type of experimental subject. In one set of experiments digestibilities were compared in two types of subjects (1, 2). Dogs were employed in several laboratories in some of the very early work (3, 4). The first intensive studies were conducted in the laboratories of the Office of Home Economics of the U. S. Department of Agriculture, by Langworthy, Holmes and Deuel, who reported the digestibilities in adult humans of a wide variety of natural and hydrogenated fats in a series of publications over a period of more than ten years (5-16). Their work, a large portion of which was done during the fat shortage following the first World War, included practically every fat which could be considered a potential source of food. More recently there has been a series of publications by Hoagland and Snider of the Animal Nutrition Division, Bureau of Animal Industry of the U.S.D.A., reporting the digestibilities of some of the more common animal and vegetable fats, shortenings, and several synthetic saturated triglycerides in albino rats (17-21). One of the most significant investigations to date was con-

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ducted in the Department of Pediatrics of Johns Hopkins University. In this series of experiments Holt and Tidwell and their associates used human infants as experimental subjects and made some very interesting observations (22-24). In a series of experiments at the University of Pittsburgh on the digestibility of some high melting shortenings, comparisons were made between two different types of experimental subjects, adult humans and albino rats (1, 2).

Correlation Between Different Types of Experimental Subjects

It appears to have been more or less tacitly assumed throughout all these investigations that the coefficient of digestibility found for a fat with any given experimental subject could be used to predict the digestibility of that fat in any other type of experimental subject. However, no attempt has ever been made to establish this assumption statistically. In order to make such a correlation we have assembled the data found in the literature, and in Table I are shown the data for those fats whose digestibilities have been reported in two or more types of experimental subjects. Certain trends may be observed by inspection of the table, but the variations introduced by inherent experimental errors introduce a confusion which prevents an accurate assessment of the relationship by this crude means. For that reason we have plotted the data for the two groups of subjects which have been used most extensively, adult humans and albino rats, in Figure 1. Now the true correlation becomes more apparent. The coefficient of correlation, calculated by the equation:

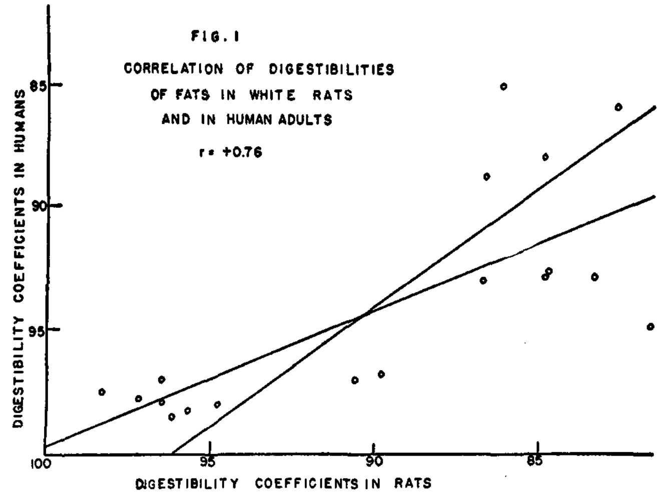
$$r = \frac{\Sigma X_1 X_2}{\sqrt{(\Sigma X_1^2)(\Sigma X_2^2)}} \qquad (26)$$

is + 0.76, which is a relatively strong positive correlation for biological work of this nature. It becomes especially significant in view of the fact that the data used were collected in a number of different laboratories by a variety of techniques, which rules out the usual consistency of error.

For a better visual appreciation of the significance of the r value, the regression of each digestibility on the other has been calculated and the curves obtained are shown in the figure. If there were no correlation at all, the two lines would be perpendicular; perfect correlation results in coincident curves (26). It is evident that the two curves more closely approach the latter, indicating good correlation. Thus it may be concluded that the coefficients of digestibilities of fats found for albino rats may be used to predict the digestibilities of these fats in adult humans, and vice versa. In other words, if two fats are equally digestible in rats, they are probably equally digestible in humans; and if fat A is more digestible than fat B in the one group, it will probably be more digestible in the other. There is no apparent reason why this conclusion cannot be extended to include other experimental subjects.

Factors Affecting the Digestibility of Fats

In all the literature to date it has been shown that fats as a class are well digested by any of the experimental subjects, the majority being more than 90% assimilated. Various characteristics of fats have been proposed as the factor which causes the variations which do exist. Without reciting the whole list, we

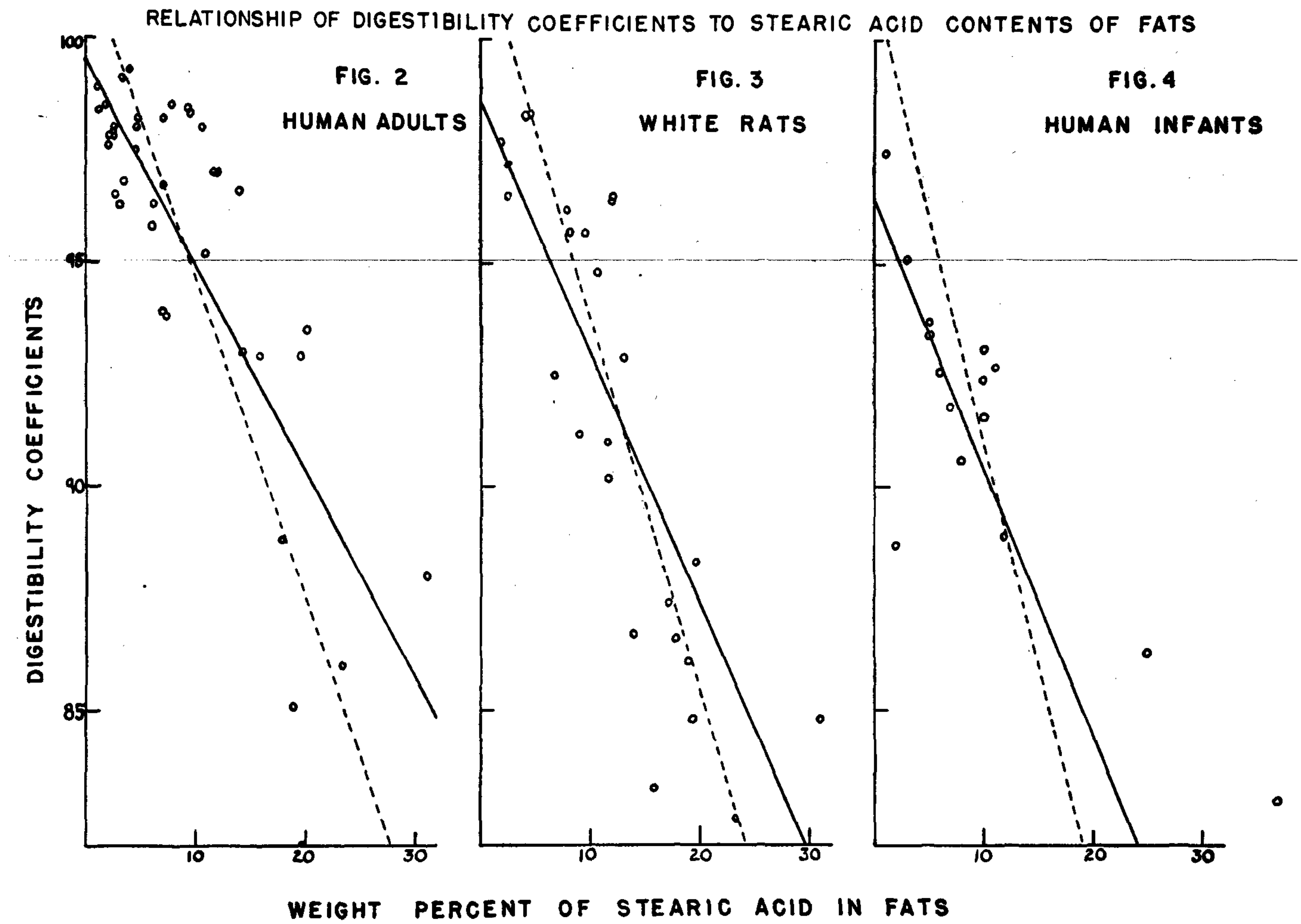


will refer here only to the two which have been most often suggested. In the early work of Langworthy, Holmes, and Deuel it was repeatedly concluded (5, 14, 15) that an inverse relationship existed between the digestibility of fats and their melting points. To quote from one of their later papers which was a review of their work to that time (15), "the observed data seem to warrant the conclusion that the thoroughness of digestion is inversely proportional to the melting point."

The above hypothesis has persisted and still is occasionally referred to even though there have been numerous publications in the literature which suggested that the inverse proportionality which apparently exists with melting point is coincidental and not an evidence of true causal relationship. Thus, as early as 1917 Lyman (3) suggested "that the melting point of the ester is not the only factor, probably not the chief factor, determining the rate of hydrolysis and absorption." He suggested "that the nature of the fatty acid radical of an ester has an effect on digestibility aside from its effect upon the melting point of the compound." From their work on the digestibility of animal and vegetable fats in albino rats Hoagland and Snider (20) observed that "it is apparent that some factor other than the melting point determined the relative digestibility of these fats, possibly their stearic acid content." It has been shown by Mattil and Higgins (25) that stearic acid is almost entirely undigested by albino rats when fed as tristearin mixed with triolein, and only slightly more digestible when fed in the mixed glycerides distearo-monoölein and dioleomonostearin. This same effect of tristearin has been reported by Hoagland and Snider (21), who found its digestibility to be of the order of 6 to 8%, while tripalmitin was 82 to 84% and trimyristin and trilaurin completely assimilated by albino rats.

From experiments with human infants Holt and Tidwell and their collaborators (22-24) concluded that "no single factor in the composition of a fat can be taken as an index of retention; the composition of the whole must be considered. Individual fatty acids are selectively absorbed when a mixed fat is fed." They calculated the following digestibilities for the various fatty acids in normal fat mixtures:

Unsaturated acids	98%
Short chain saturated	90%
Palmitic	88%
Stearic	60%
Longer than stearic	40%



From the above discussion it becomes evident that saturated acids of 18 or more carbons constitute the factor which limits the digestibility of fats. Inasmuch as those with more than 18 carbons represent minor constituents of fats, we shall include them with stearic acid in our discussion; i.e., when we speak of ''stearic acid'' we refer to all saturated acids of 18 or more carbons.

In order to determine how much correlation exists between the ''stearic acid'' content of fats and their digestibility, we have assembled the major portion of the available data for fats whose fatty acid compositions were reported or could be estimated. Thus, if the analysis for a specific fat such as cottonseed oil was not reported along with its digestibility, we have arbitrarily assigned to that oil an accepted analysis reported elsewhere in the literature. Obviously, this will lead to some small error due to the natural variation of oils, but we feel that a sufficiently large number of samples has been used to make our calculations reliable. The data are presented graphically in Figures 2, 3, and 4.[1]

The first group of data show the digestibilities in adult humans of a group of forty fats. These data have been treated statistically as described above, the calculated correlation being —0.80. Thus, it is quite evident that an inverse relationship exists between the digestibilities of the forty fats and their ''stearic acid'' contents. Nearly as good correlation was found for the data for human infants. Here the coefficient was —0.77, calculated for 16 fats. The best correlation has been obtained with albino rats. The figure includes data for 26 fats, and for these the coefficient is —0.86. If we include in the calculation five fats whose digestibilities have been reported but are too low, because of their very great stearic acid contents, to be included in the figure, the coefficient becomes —0.96, which is nearly perfect.

Certain generalizations may be drawn from these three figures and from the preceding discussion of the literature. Quite obviously, as the ''stearic acid'' content of the fats increased, their digestibilities decreased. The solid line in each of the figures represents the equation calculated for the regression of digestibility on ''stearic acid'' content. The variations from this line are probably due to a combination of experimental error and the variable effect of the other fatty acids of the fats. Thus, a fat with little stearic acid but a high percentage of shorter saturated acids would fall below the curve whereas a fat with relatively minor proportions of shorter saturated acids probably would be above the curve. In general this has been found to be true.

From the intercepts and the slopes of the solid lines it may be observed that the three types of experimental subjects exhibited variable degrees of sensitivity to ''stearic acid.'' The adult humans appear to metabolize portions of the ''stearic acid'' most

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[1] In Figs. 2, 3, and 4 the solid line represents the equation calculated for the regression of digestibility on "stearic acid" content; the dotted line, regression of "stearic acid" content on digestibility. As in Fig. 1, the more closely the two lines approach coincidence, the higher the degree of correlation.

TABLE I

Digestibilities of Some Fats in More Than One Type Experimental Subjects

Fat	Human	Digestibility Coefficient		
		Rat	Infant	Dog
Vegetable Oil T	98.5[1]	96.2[2]	......	......
Peanut Oil	98.3[6]	95.7[17]	......	......
Butter	98.0[1]	94.8[2]	......	......
Coconut Oil	97.9[6]	96.5[20]	88.7[22]	......
Olive Oil	97.8[6]	......	95.1[22]	......
Cottonseed Oil	97.8[6]	97.2[17]	......	98.8[4]
Soybean Oil	97.5[9]	98.3[20]	93.7[22]	......
Butter	97.0[5]	90.6[20]	88.9[22]	......
Lard	97.0[5]	96.5[17]	......	97.8[4]
Lard	......	96.4[18]	......	96.6[3]
Corn Oil	96.8[9]	98.3[20]	......	98.9[4]
Oleo Oil	96.8[10]	89.8[17]	......	......
Cacao Butter	94.9[6]	81.6[20]	......	......
Oleo Stock	93.0[5]	86.7[20]	......	......
Shortening L	92.9[1]	84.8[2]	......	......
Shortening P	92.9[1]	83.3[2]	......	......
Shortening M	92.6[1]	84.7[2]	......	......
Shortening X	88.8[1]	86.6[2]	......	......
Mutton Tallow	88.0[5]	84.8[20]	......	......
Shortening S	86.0[1]	82.6[2]	......	......
Shortening R	85.1[1]	86.1[2]	......	......

readily, with very few fats being less than 92% digestible. Rats are intermediate in their utilization of the long chain saturated acids while the human infants evidently are the most sensitive. In fact, the evidence indicates that the latter do not utilize completely any of the saturated acids but show a marked preference for the unsaturated; for example, premature infants and twins showed higher digestibility coefficients and better growth with olive oil and soybean oil which contain predominantly unsaturated acids than with butter-fat which consists largely of short chain saturated acids (24).

To refer again to the apparent relationship between the digestibilities of fats and their melting points, their coefficients of correlations have been calculated for human adults and for albino rats. In the case of the former it was —0.66 for 37 fats and in the latter it was —0.42 for 24 fats. These are to be compared with the —0.80 and —0.86 found in the correlation of digestibility with "stearic acid" composition. The majority of the 37 fats used in calculating the —0.66 correlation in human adults were from several series of fats hydrogenated to various melting points (15), in which there should be even closer relationship between "stearic acid" content and melting point than in randomly selected natural and hydrogenated fats. This undoubtedly accounts for the fact that the correlation for humans was so much better than that for albino rats. Thus it seems apparent that the correlation which does exist between the digestibility of fats and their melting points depends upon the effect of the saturated acids upon the melting points, and as a result is merely a secondary effect. The primary factor which limits the digestibility of fats is, without doubt, the amount of saturated fatty acids present, and the degree of limitation increases with chain length.

Summary

It has been shown by statistical analysis that a positive correlation exists between digestibilities found in human adults and those found for corresponding fats in albino rats. The general limiting factor of digestibility of a fat is the amount of saturated fatty acids present, but the extent of limitation is dependent upon the adaptability of the subject. It is concluded as a general rule that the amount of saturated acids of 18 or more carbons is the chief limiting factor. This fact readily accounts for the lesser degree of correlation which exists between digestibility and melting point, the latter being partially a function of the amount of long chain saturated acids.

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