Usable Energy Value of Jojoba Oil[1]

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ABSTRACT

For possible use in reduced-calorie baked foods, jojoba oil was assessed for its usable energy value. Weanling rats were fed diets where soybean oil, 24% of the diet, was increasingly replaced with jojoba oil. At levels up to 9% jojoba oil in the diet, the lean body mass (protein-water-ash matrix) of the rats was little affected, while their body fat content declined substantially. Based on these and other response parameters measured (e.g., efficiency of conversion of ingested energy to carcass energy), jojoba oil was estimated to contain very little usable energy.

Reduced-calorie foods represent one of the fastest growing segments of the food industry in the United States today. Ingredients that permit this are being sought and developed vigorously. Nonnutritive sweeteners, emulsifiers, and bulking agents are good examples of ingredients that are currently used in the production of these reduced-calorie foods. Jojoba oil, a wax ester with little, if any, triglycerides (Clark and Yermanos 1980, Utz et al 1982), may prove to be another such ingredient.

Jojoba oil is obtained from the seeds of the jojoba plant (*Simmondsia chinensis*) which is now widely grown in the Sonoran Desert region of North America. Clark and Yermanos (1980) report the mean oil content of several collections of jojoba seeds to be 53.2%. Jojoba oil is resistant to oxidation and exhibits a high viscosity index and a high flash point. Currently, most of the jojoba oil produced in the United States is used as an industrial lubricant and in cosmetic products. Jojoba oil is bland to taste and contains no off flavors and, thus, could find use in food products.

Because jojoba oil is a nontriglyceride and therefore is likely to be poorly metabolized during digestion, it is being promoted by some as a low-calorie fat for use as salad or cooking oil (Haumann 1983). Jojoba oil may also be of value as a partial substitute for fat in high-fat bakery foods. As a prelude to this possible use, the current studies were undertaken to assess the usable energy value of jojoba oil.

MATERIALS AND METHODS

Test Oils

Food-grade soybean oil (SBO) and jojoba oil (JO; obtained from SO-CAL Jojoba Inc., Riverside, CA) were used as the source of reference and test oil, respectively.

Test Diets

Five test diets were formulated in each of the two experiments conducted. In these experiments, SBO initially constituted 24% of the diet, and increasing amounts of JO were substituted (Table I). Such substitution was eventually total in experiment I but only partial (50%) in experiment II (Table I). All test diets were complete in nutrients required by the rat (NAS/NRC 1978), with protein providing 11% of the total calories, fat 43% (diets A and AA), and carbohydrates 46%.

Animals and Feeding

Because of the relative ease of whole body chemical analysis, rats (male weanling rats of Sprague-Dawley strain obtained from Harlan Sprague-Dawley, Indianapolis, IN) were used as the test model. They were housed individually (10 rats/diet) in mesh-bottom stainless steel cages in a controlled (24°C, 12 hr of light) environment. In experiment I, the groups of rats were fed ad libitum. In experiment II, the feeding was restricted and equaled the ad libitum intake observed on diet EE, which was consumed in the least amount (Table II). Each experiment lasted three weeks. Deionized water was supplied to the rats ad libitum throughout, and body weight and diet intake records were kept.

Carcass Sampling

At the end of the feeding phase, all rats in experiment II were sacrificed, their gut contents removed and discarded, and the carcasses weighed and then frozen pending analyses. For compositional analyses, carcasses were individually autoclaved (121°C, 15 psi, 1.5 hr) in excess water, thoroughly homogenized in a Waring Blendor, freeze-dried (48 hr), and finely ground; then suitable aliquots were taken for analysis. Rats in experiment I were not analyzed but they were also sacrificed and their livers removed, thoroughly blotted, and weighed.

Analytical

The carcasses and test diets were analyzed for moisture, protein (Kjeldahl N), fat (acid hydrolyzed), and ash using standard AACC methods (1983). Carbohydrate values were determined by difference.

Statistical

The data in Tables II–IV were analyzed statistically by analysis of variance (Snedecor and Cochran 1980) and by Duncan's (1955) multiple-range test. Data in Table V were derived, in part, from a regression equation (discussed later).

RESULTS AND DISCUSSION

The test diets in both experiments contained a substantial amount of fat (43% of the total calories) provided as SBO or JO or both (Table II). This level of fat, however, is not excessive compared to the current United States diet (U.S. Senate 1977). While SBO and other highly digestible fats and oils may cause no experimental difficulties at high intakes, such was not the case with

TABLE I
Composition of Test Diets

Component	Experiment I					Experiment II				
	A	B	C	D	E	AA	BB	CC	DD	EE
Soybean oil (g)	24	18	12	6	0	24	21	18	15	12
Jojoba oil (g)	0	6	12	18	24	0	3	6	9	12
Others[a] (g)	76	76	76	76	76	76	76	76	76	76
Energy[b] (kcal/g)	4.85	4.85	4.85	4.85	4.85	4.85	4.85	4.85	4.85	4.85

[a]Casein, 15; vitamin diet fortification mixture (in dextrose base) from ICN Pharmaceuticals, 2.2; mineral mixture (contained Zn, 1.2 mg; Mn, 5 mg; Mg, 40 mg; Fe, 3.5 mg; Cu, 0.5 mg; and I, 0.015 mg in sucrose base), 0.5; NaCl, 0.13; KCl, 0.69; $CaSO_4 \cdot 2H_2O$, 2.15; NaH_2PO_4, 1.55; DL-methionine, 0.1; sucrose, 26.84; and pregelatinized wheat starch, 26.84. Casein contained 89% protein.

[b]Gross energy calculated using the following heat of combustion values (kcal/g): 9.0 for fat, and protein, starch, and sucrose 4.0 each.

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TABLE II
Diet Intake and Growth Responses of Rats[a] (three-week experiments)

Variables and Responses	Experiment I A	B	C	D	E	Experiment II AA	BB	CC	DD	EE
Jojoba oil (% of diet)	0	6	12	18	24	0	3	6	9	12
Diet intake (g)	220 a	215 ab	207 b	229 a	151 c	182 a	182 a	181 a	181 a	180 a
	±16	±10	±12	±11	±2	±6	±9	±3	±11	±6
Body weight gain[b] (g)	108 a	101 a	74 b	61 c	15 d	73 a	71 a	64 b	59 b	42 c
	±11	±5	±11	±8	±3	±5	±5	±4	±6	±9
Gain/intake ratio	0.49 a	0.47 a	0.36 b	0.27 c	0.10 d	0.40 a	0.39 a	0.35 b	0.33 b	0.23 c
	±0.03 a	±0.01 a	±0.04	±0.03	±0.02	±0.02	±0.02	±0.02	±0.03	±0.05
Liver weight[c] (g)	8.8 a	8.4 a	5.3 b	4.3 c	2.3 d	...	...	...	...	...
	±1.0	±0.9	±0.7	±0.5	±0.3					

[a] Values are averages (9–10 rats/diet except diet E) ± standard deviation. Averages in each line followed by the same letter were not statistically different ($P > 0.05$). Values for diet E are based on two-week feeding only and rats that survived.
[b] Initial body weights (g/diet) averaged 48 ± 3 in experiment I and 54 ± 6 in experiment II. Unlike experiment II, rats in experiment I were fed ad libitum.
[c] Fresh weights. Livers were not removed in experiment II.

TABLE III
Whole Body Composition of Rats[a]

Component	Diet AA	BB	CC	DD	EE
Jojoba oil (% of diet)	0	3	6	9	12
Carcass					
Weight[b] (g)	122.4 ± 7.7 a	120.7 ± 7.4 a	111.6 ± 4.9 b	103.8 ± 9.1 c	87.2 ± 6.5 d
Water (g)	80.5 ± 4.8 a	80.0 ± 5.5 a	74.6 ± 3.4 b	70.9 ± 4.7 b	60.9 ± 4.6 c
Protein (N × 6.25, g)	21.7 ± 1.2 a	22.6 ± 1.0 a	21.4 ± 1.1 a	21.4 ± 3.6 a	18.2 ± 1.9 b
Fat (g)	14.9 ± 2.9 a	13.7 ± 2.4 a	11.0 ± 1.3 b	7.3 ± 2.1 c	4.3 ± 0.7 d
Ash (g)	3.8 ± 0.3 a	3.9 ± 0.3 a	3.8 ± 0.3 a	3.6 ± 0.7 a	3.2 ± 0.4 b
Glycogen[c] (g)	1.5 ± 0.8 a	0.5 ± 0.4 b	0.8 ± 0.6 b	0.5 ± 0.4 b	0.6 ± 0.4 b

[a] Values are averages (9–10 rats/diet) ± standard deviation. Averages in each line followed by the same letter were not statistically different ($P > 0.05$).
[b] With gut contents discarded.
[c] Values represent the remainder of the sum of other listed components subtracted from total carcass weight.

TABLE IV
Caloric Efficiency in Jojoba Oil-Fed Rats[a]

Variables and Responses	Diet AA	BB	CC	DD	EE
Jojoba oil					
% of Diet	0	3	6	9	12
% of Substitution[b]	0	12.5	25	37.5	50
Energy intake[c] (kcal)	881 a	880 a	878 a	876 a	874 a
	±27	±42	±15	±54	±27
Total carcass energy[d] (kcal)	227.0 a	215.5 a	187.6 b	153.6 b	114.1 d
	±27.6	±22.9	±13.3	±32.0	±12.2
Caloric efficiency[e] (%)	25.7 a	24.5 a	21.4 b	17.5 c	13.0 d
	±2.5	±2.2 a	±1.5	±2.9	±1.2
Loss of caloric efficiency (%)	0.0 a	4.7 a	16.9 b	31.9 c	49.3 d
	±9.7	±8.5	±5.8	±11.3	±4.5 d

[a] Values are averages (9–10 rats/diet) ± standard deviation. Averages in each line followed by the same letter were not statistically different ($P > 0.05$).
[b] Substitution for soybean oil, 24% of the diet, with jojoba oil.
[c] Total energy intake in three weeks.
[d] Factors (kcal/g) used: Fat, 9; protein and glycogen, 4 each.
[e] Conversion of calculated energy intake to carcass energy.
[f] Relative to diet AA and based on caloric efficiency.

JO. In experiment I, when JO replaced SBO in excess of 50% (diets D and E, Table I), it produced an extreme laxative effect in the rats with resultant extensive coating of their body surface with JO. This jeopardized the animal's well being. Frequent washing of the rats ensured survival but only of those fed diet D. On diet E (all JO), only three rats survived by week two when this diet was discontinued.

Because of experimental difficulties encountered in experiment I, a second experiment (experiment II) was undertaken in which the progressive substitution of SBO with JO was of a lesser magnitude and limited to a maximum of 50% (Table I).

TABLE V
Loss of Caloric Efficiency as a Function of Jojoba Oil in the Diet

Jojoba Oil (% Substitution)[a]	Loss of Caloric Efficiency (%) Determined Values	Equation-Based Values
0	0.0	...
12.5	4.7	8.0
25	16.9	20.6
37.5	31.9	33.1
50.0	49.3	45.7
100	ND[b]	96.0

[a] Percent substitution for soybean oil in the diet.
[b] Not determined.

Diet Intake and Growth Responses

When rats were fed ad libitum (experiment I), their intakes gradually declined initially (Table II). Probably to compensate for low usable calories in JO, diet intake then increased (diet D) but then declined again. In both experiments, the body weight gains of rats progressively declined as JO was increasingly substituted for SBO. In experiment II, this occurred even when the diet intake between groups of rats was equalized; obviously, the calories in JO were poorly available. The steady decline observed in gain/intake ratios and liver weights are also strongly suggestive of poor availability. The adverse effect of JO on response parameters listed in Table II was most dramatic when at least half of the SBO was substituted (diets A vs. C and AA vs. EE).

Body Composition of Rats

Like live weights (Table II), carcass weights of the rats progressively declined as SBO in the diet was increasingly replaced with JO (Table III). Carcass fat deposition also declined progressively and substantially; on nearly identical caloric intakes (Table IV), rats fed diet EE (half SBO, half JO) showed about 70% decline in body fat content as compared to diet AA (all SBO). In contrast, the protein and ash contents of the carcass changed little up to 9% JO in the diet, and the decline in carcass water content became profound only when JO in the diet exceeded 9% level (Table III). This suggests that the lean body mass of the growing rats was not adversely affected. Such may not be the case when JO is consumed in excess as the data on diet EE suggest (Table III).

Caloric Efficiency of Jojoba Oil

A number of dietary factors affect the efficiency of utilization of ingested energy (Schemmel et al 1972, Mateos and Sell 1980). In our studies, the source of oil was the only dietary factor studied. The diet intake (Table II), and thus the energy (gross) intake (Table IV) of rats was kept constant (experiment II). Under these conditions, the progressive decline observed in total carcass energy as the level of JO in the diet increased indicated that JO was quite poorly utilized (Table IV). Caloric efficiency values (conversion of ingested gross energy to carcass energy) listed in Table IV are strongly suggestive of this. Percent caloric efficiency declined from a value of 25.7 ± 2.5 on the all-SBO-based diet (diet AA) to a value of 13.0 ± 1.2 when the diet contained half SBO and half JO (diet EE).

Loss of Caloric Efficiency

Compared to the all-SBO-based diet, the percent loss of caloric efficiency increased progressively as SBO in the diet was increasingly replaced with JO (Tables IV and V). Using the magnitude of this loss as a function of JO in the diet, a regression equation was calculated:

$$Y = -4.6 + 1.0064\ X.$$

Here Y represents the percentage loss of caloric efficiency, −4.6 is the Y intercept, 1,0064 is slope of the line, and X represents the percent substitution of SBO by JO listed in Table IV.

In experiment II, SBO was replaced with up to 50% JO; because of the experimental difficulties encountered in experiment I, total replacement was not effected. Extrapolating from the regression equation, total replacement of SBO with JO would cause a 96% loss of caloric efficiency (Table V). This means that only 4% of the calories in JO may be usable. A different experimental approach to determine usable energy in JO may yield somewhat different values, but it is unlikely that JO would provide any significant amount of usable calories. Thus, JO may be an effective, although only partial, substitute for fat in food products traditionally high in fat. To fully realize this possibility, toxicological and product evaluation studies on JO are, however, still needed.

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