Effect of Fat Sources on Satiety

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Abstract

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Objective: There are inconsistent reports on the satiety value of different fatty acids. This study compared the appetitive effects of two fat sources rich in monounsaturated fatty acids (peanut oil and canola oil) with a source rich in saturated fatty acids (butter).

Research Methods and Procedures: After an overnight fast, lean participants completed a questionnaire eliciting information about hunger, fullness, desire to eat, and prospective consumption. They then consumed one of the preloads (muffins containing 40 g of each fat source or no fat) and 150 mL of water within 15 minutes. Questionnaires were completed again 30, 60, and 120 minutes after preload ingestion. Participants kept dietary records during the subsequent 24 hours.

Results: Canola and peanut oil muffins resulted in higher fullness, and butter, canola, and peanut oil muffins resulted in lower hunger ratings 30, 60, and 120 minutes after preload ingestion compared with the fat-free preload. No differences were observed among the fat-containing loads. Although energy intake 24 hours after consumption of the preloads was also comparable on days the three fat-containing loads were consumed, energy consumption after each study session was higher when the fat-free muffins were provided. However, total energy intake, including the calories provided by the preloads, was similar across treatments.

Discussion: These data do not support a differential satiety effect of fat sources rich in monounsaturated fatty acids relative to one rich in saturated fatty acids.

Key words: satiety, monounsaturated fatty acids, saturated fatty acids, caloric intake

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Introduction

The increasing prevalence of overweight and obesity has prompted study of the contributory role played by dietary fat (1–7). One line of evidence indicates that fat's high energy density and palatability contribute to passive overconsumption (8,9); that is, fat holds weak satiating and satiety properties (10,11). Other work indicates that fat intake evokes little oxidative response, thereby facilitating its storage (12–14). Integration of these areas has recently stimulated interest in potential differential satiety roles for individual fatty acids, because they vary in efficiency of absorption and rate of oxidation.

French et al. (15) reported that nasogastric infusion of oil emulsions led to no differential satiety response in humans. However, linoleic acid resulted in significantly lower postloading energy intake compared with saline. Subsequently, Lawton et al. (16) compared the effect of the degree of saturation on postingestive satiety in a preload study. They observed a weaker effect of monounsaturated fatty acids (MUFAs)[1] on prospective consumption ratings than polyunsaturated fatty acids (PUFAs). Ratings of hunger, desire to eat, and fullness did not differ. In a second study conducted by the same investigators, the effects of these fatty acids were not significantly different on any appetitive index. Recently, Kamphuis et al. (17) also reported no effect on energy intake after 2 weeks of consumption of PUFAs (linoleic acid, γ-linoleic acid) or MUFAs (oleic acid).

The purpose of this study was to further clarify this issue by contrasting the satiety effects of fat sources high in MUFAs (peanut oil and canola) with those high in saturated fatty acids (SFAs; butter).

Research Methods and Procedures

Design

After a 10-hour overnight fast, participants completed baseline questionnaires eliciting information about mood and appetitive sensations. Questions about mood were asked to distract the participants from the main purpose of the study. After questionnaire completion, participants con-

[1] Nonstandard abbreviations: MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; SFA, saturated fatty acid; OA, oleic acid.

sumed within 15 minutes one of four preload muffins and 150 mL deionized water. The 4 preload muffins were administrated in random order at weekly intervals. For the following 2 hours, participants stayed in the laboratory and completed the appetitive questionnaire 30, 60, and 120 minutes after preload ingestion. Participants kept free-feeding dietary records over the 24 hours after preload ingestion. The protocol was approved by the Human Subjects Review Committee of Purdue University.

Participants

A total of 20 (9 men and 11 women) students and staff were recruited by public advertisement. All were healthy adults (24.7 ± 7.8 years of age), with a mean body fat of 20.6 ± 7.2% (measured by bioeletrical impedance analysis, model TBF-105; Tonita, Skokie, IL) and a mean body mass index of 21.6 ± 2.1 kg/m^2. Eligibility criteria included nonsmoker, not using medication (except birth control pills), not pregnant or lactating, not on a therapeutic diet, regular eating habits, no weight loss or gain >3 kg over the previous 3 months, normal fasting blood glucose (70–110 mg/dL), no peanut allergy, no family history of diabetes, and dietary restraint ≤14 (18).

Preload

Ten additional nonstudy participants evaluated the muffins in terms of pleasantness (taste, smell, texture, overall appearance) and taste intensity (sweet, sour, bitter, salty) using 9-point category scales. No statistically significant differences were found for ratings of fat level for muffins containing canola oil, peanut oil, or butter. However, fat-free muffins differed from canola oil muffins [$F(1,9) = 9.309$, $p = 0.014$)], peanut oil muffins [$F(1,9) = 20.376$, $p = 0.001$)], and butter muffins [$F(1,9) = 9.309$, $p = 0.014$)] when they were rated for fat level. The mean fat level ratings for muffins containing no oil, canola oil, peanut oil, or butter were 2.0, 4.9, 5.3, and 4.5, respectively.

On each testing occasion, participants were given one of three identical muffins comprised of a total of 75.5 g of fat-free cake mix (Duncan Hines; Angel Food, Columbus, OH), 5 g of unsweetened cocoa (Hershey Foods, Hershey, PA), 25 mL of water, and 40 g of either peanut oil (Holliwood, Uniondale, NY), canola oil (Crisco, Cincinnati, OH), or salted butter (Land O Lakes, Arden Hills, MN). A control preload containing no fat was also tested. All the muffins contained the same approximate volume (230 mL). Fat-containing muffins weighed ~73 g and no-fat muffins weighed 59 g. Additional characteristics of the preloads are shown in Table 1.

Table 1. Weight and nutritional characteristics of the preloads

	Type of fat source in the muffin			
	Butter	Canola	Peanut oil	No fat
Approximate weight (g)	73	73	73	59
Approximate volume (mL)	230	230	230	230
Nutrients:				
Total lipids (g)	30.77	38.24	38.04	0
SFA (g)*	20.20	2.84	6.76	0
PUFA (g)*	1.20	11.84	12.8	0
MUFAs (g)*	9.36	23.56	18.48	0
OA (g)*	8.16	22.44	17.92	0
Ratios:				
PUFA:SFA	0.059	4.169	1.893	0
OA:PUFA	6.80	0.95	0.96	0
Energy (kcal)	516.93	584.16	582.36	240
Percentage kilocalories from fat	53.57	58.92	58.79	0
Calorie density (kcal/g)	7.08	8.00	7.98	4.07

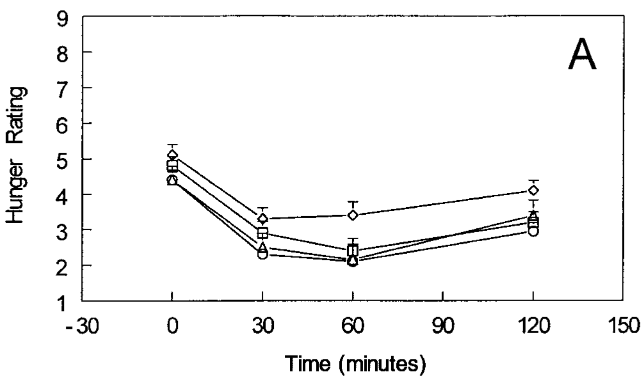
* U.S. Department of Agriculture, Agricultural Research Service, 1999. USDA Nutrient Database for Standard Reference, Release 13. Nutrient Data Laboratory *http://www.nal.usda.gov/fnic/foodcomp.*

Hunger Rating

Hunger was recorded on a 9-point category scale with end anchors of "not at all hungry" and "extremely hungry." Ratings of fullness, desire to eat, and prospective consumption (how much participants thought they could eat at the time of rating) were also obtained. In addition, participants indicated the strength of their desire to consume foods representing various nutrient content and sensory properties from a list of 39 items, derived from each of the Food Guide Pyramid food groups.

Diet Records

During their first visit to the laboratory, all participants were trained to keep free-feeding dietary records. Plastic food models were used for estimation of portion size. Participants were instructed to record condiments in terms of teaspoons. After each session, participants received a standardized record form to record the type and amount of foods and beverages consumed over the 24-hour postloading period. Each dietary record was reviewed with the participant to ensure accuracy and completeness. For analysis, an eating occasion was considered to be a meal when the participants ate >300 kcal. Snacks were defined as eating occasions when participants ate ≤300 kcal. The diet records were analyzed by a single individual using the Food Processor Nutrition Analysis Software package, version 7.60 (ESHA Research, Salem, OR).



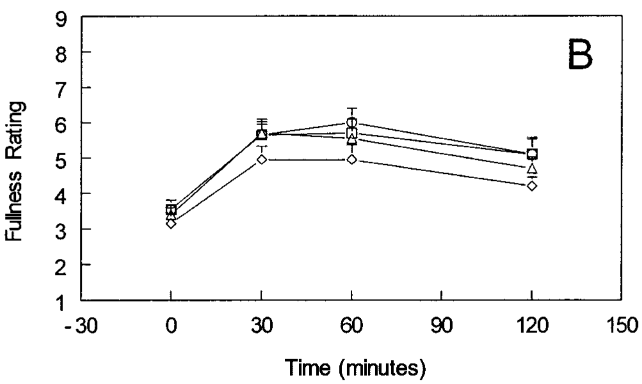


Figure 1: Mean ± SE hunger (A) and fullness (B) ratings after an overnight fast (time 0) and at different times after the ingestion of the preloads (n = 20). Values (A) for the fat-free muffins are statistically different from butter ($p < 0.03$), peanut oil ($p < 0.05$), and canola oil ($p < 0.005$) at 30, 60, and 120 minutes. Values (B) for the fat-free muffins are significantly different from canola oil ($p < 0.01$) and peanut oil muffins ($p < 0.02$). △, butter; ○, canola oil; □, peanut oil; ◇, fat free.

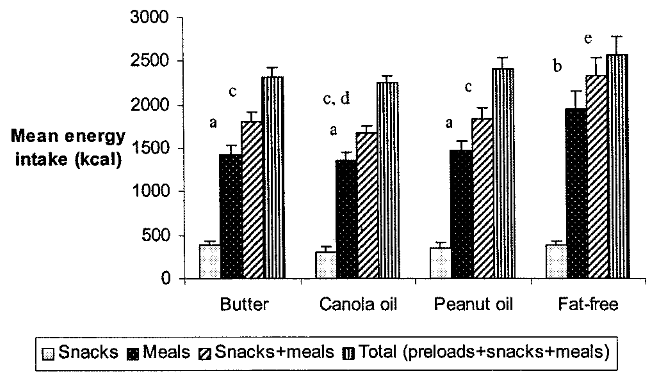


Figure 2: Mean total energy intake (kcal) ± SE provided by snacks (≤300 kcal), meals (>300 kcal), and preloads. Values a and b ($p < 0.015$), c and e ($p \leq 0.05$), and d and e ($p = 0.005$) are significantly different.

Statistical Analyses

A within-subject cross-over design was used. Appetitive sensations and energy intake analyses were conducted by repeated measures ANOVA. Paired Student's *t* tests were used for post hoc comparisons. Analyses were carried out with SPSS 10.0 for Windows (SPSS Inc., Chicago, IL). Probability values below 0.05 were considered statistically significant. The results are reported as means ± SE.

Results

Mean hunger and fullness ratings before (time 0) and after the ingestion of the preloads are shown in Figure 1. Hunger ratings after the consumption of the fat-free muffins were significantly higher than those after the consumption of the canola oil muffins [$F(7,133) = 13.964$, all $p < 0.005$)], peanut oil muffins [$F(7,133) = 12.417$, all $p < 0.05$)], and butter muffins [$F(7,133) = 17.401$, all $p < 0.03$)] at 30, 60, and 120 minutes. Areas under the curve values associated with the fat-free muffins also were higher than those associated with the fat-containing muffins. No significant differences were observed for ratings after each of the fat-containing muffins. Mean fullness ratings for canola oil [$F(7,133) = 12.822$, $p < 0.01$] and peanut oil muffins [$F(7,133) = 12.092$, $p < 0.02$] were significant higher 30, 60, and 120 minutes after ingestion relative to ratings after fat-free muffin ingestion. The mean fullness rating after ingestion of the butter muffins was significantly higher than after consumption of fat-free muffins only at 30 minutes. No differences were observed among the fat-containing muffins. No statistically significant differences were found for desire to eat or prospective consumption ratings across treatments.

Mean total energy intake (kilocalories), including the calories provided by snacks (≤300 kcal), meals (>300 kcal), and preloads is shown in Figure 2. Although no difference was observed for the number of snack (1.9, 1.87, 1.8, and 2.1 for butter, canola oil, peanut oil, and fat-free muffins, respectively) or meal (4.1, 4.3, 4.5, and 4.5 for butter, canola oil, peanut oil, and fat-free muffins, respectively) eating episodes, meal energy intake 24 hours after ingestion of the fat-containing muffins was significantly lower [$F(3,57) = 6.410$, $p < 0.0015$] compared with meal ingestion after the fat-free muffins. When the number of calories ingested as snacks and meals were included, daily energy intake was lower on days the muffins containing butter [$F(1,19) = 4.455$, $p = 0.05$], peanut oil [$F(1,19) = 8.292$, $p = 0.01$], or canola oil [$F(1,19) = 11.626$, $p = 0.005$] were consumed compared with the days the fat-free muffins were consumed. However, no difference in daily caloric intake was observed when the number of calories ingested 24 hours after each study session was added to the calories provided by the preloads.

Hunger ratings and food intake did not differ by gender. No significant difference was noted for ratings of the desire to consume foods from the list of 39 items representing various nutrient content and sensory properties.

Discussion

High-fat, energy-dense foods with weak satiating and satiety properties may contribute to positive energy balance in a setting where they are affordable and palatable (19). However, it has been proposed that this may be modulated by their fatty acid composition (15,16). The degree of oxidative metabolism of different free fatty acids in the liver constitutes a significant source of information for the control of appetite (20). Studies in rats indicate that fat that is oxidized is satiating, whereas fat that is stored is not (21).

The saturation level of fatty acids influences their melting points and pH, which, in turn, can affect the rate of absorption (22). In rats, saturated and transunsaturated fatty acids are less efficiently absorbed from the gut than unsaturated fatty acids (23). Furthermore, oleic acid (OA; 18:1n-9) is more rapidly absorbed and oxidized than stearic acid (18:0) (24). In humans, PUFAs (25,26) are oxidized faster than SFAs. Thus, SFAs should be favored for deposition (25,27–29) and hold weaker satiety properties. Lawton et al. (16) suggest that MUFAs containing a high percentage of OA, the principle storage form of fatty acids in human adipose tissue (30), may exert relatively weak control over appetite compared with PUFAs. Thus, it could be hypothesized that the rank ordering of fatty acids with respect to satiety should be PUFAs $>$ MUFAs $>$ SFAs. However, support for this ordering is generally lacking.

The results obtained by French et al. (15) indicate that appetitive sensations were not differentially affected by fatty acids varying in saturation. Linoleic acid infusion led to a greater suppression of intake relative to OA and stearic/OA emulsion, but the greatest effect was noted with intralipid, which is not especially high in linoleic acid. Given the accumulating evidence for a gustatory component to oral fat detection and lipid metabolism (31), this finding, based on infusions that bypass oral stimulation, may not faithfully reflect responses to the tested fatty acids. Lawton et al. (16) reported that PUFAs had a stronger influence over prospective consumption than MUFAs and SFAs. However, this effect was small, of short duration, not observed on other appetite indices, and not reproducible. In the study conducted by Kamphuis et al. (17), subjects replaced all fat products with either linoleic acid, γ linoleic acid, or OA for 2 weeks. No significant differences were observed for appetitive variables (hunger, satiety, fullness, thirst, and desire to eat) among the three treatments. Twenty-four-hour energy intake was assessed, but no differences were observed among the oils.

In this study, comparable appetitive ratings were obtained after ingestion of all fat-containing muffins, further challenging the hypothesis of differential satiety effects in humans of long-chain fatty acids varying in saturation. Hunger and fullness ratings were similar for all the fat-containing muffins. Hunger ratings after consumption of the fat-free muffins were higher and the fullness ratings were lower than those after ingestion of the muffins with added fat. However, the fat-free muffins contained less total energy, an important contributor to satiety (32).

Lower 24-hour energy intake was observed after consumption of canola oil muffins. This could be attributed to the fact that canola oil has higher PUFA:SFA and lower OA:PUFA ratios than peanut oil and butter. However, peanut oil has higher PUFA:SFA and lower OA:PUFA ratios than butter, and intake after peanut oil was not significantly lower than intake after butter. Thus, our intake data also did not fit predictions.

There is no consensus in the literature about the association between the number of eating episodes per day and energy consumption. One study has reported that snacking contributed to increased energy consumption (33), whereas others have noted no relationship (34,35) or an inverse association (36). In this study, no significant difference was observed for the number of eating episodes and calorie intake. The number of calories eaten as snacks and meals 24 hours after ingestion of the fat-containing muffins was lower than after the ingestion of the fat-free muffin. However, when discretionary calorie intake was added to the energy provided by the preloads, summated intake was similar across treatments. The subjects of this study seemed to compensate for the loads of varying energy content (240 kcal for fat-free muffins compared with more than 500 kcal for the fat-containing muffins) in the total number of calories (preloads $+$ meals $+$ snacks) ingested. However, each subject's customary energy intake was not known, so the magnitude of challenge the muffins posed to each individual could not be determined. Thus, the compensatory response is only relative to the study protocol and not necessarily the more behaviorally relevant response to foods under normal eating conditions.

The substitution of reduced-fat (reduced-energy) versions of comparable higher-fat items should facilitate reduced consumption of energy and improve weight management. However, relatively little is known about how these types of foods influence patterns of food choice and consumption and whether they are indeed effective in reducing energy intake in free-living situations over extended periods of time (37). The results of this study suggest that free-living subjects have higher energy intake in the 24 hours after they are covertly served fat-free foods as their first meal of the day. This may be exacerbated if consumers are informed about the fat level of the meal (38). Should this higher energy intake after fat-free food ingestion continue on a long-term basis, weight gain will likely ensue.

Taken together, the evidence supporting differential effects of long-chain fatty acids varying in saturation on feeding in rats (25,29) has not been replicated in humans.

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