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ORIGINAL CONTRIBUTION

Combined medium-chain triglyceride and chilli feeding increases diet-induced thermogenesis in normal-weight humans

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Abstract
Background and purpose Capsaicin, the active ingredient of chilli, and medium-chain triglycerides (MCT) have been shown to increase diet-induced thermogenesis (DIT), improve satiety and decrease energy intake. Combinations of thermogenic ingredients have previously been investigated such as mustard and chilli, or capsaicin and green tea with positive effects. The aim of this study was to investigate the combined effects of chilli and MCT feeding on DIT and satiety in healthy volunteers.
Methods Seven healthy volunteers were tested on four occasions following an overnight fast. Volunteers were fed a breakfast containing chilli and MCT oil, chilli and sunflower oil, bell pepper and sunflower oil or bell pepper and MCT oil. Satiety and gastrointestinal comfort were measured using visual analogue scales (VAS) and category scales. Baseline energy expenditure, and DIT and fat oxidation were measured for 6 h using indirect calorimetry.
Results There were significant differences in DIT between the meals ($P = 0.003$) which increased from 7.0 % for pepper–sunflower oil to 10.7 % for chilli–MCT oil. The predominant differences existed between the chilli–MCT oil and chilli–sunflower oil ($P = 0.013$), between chilli–MCT oil and pepper–sunflower oil ($P = 0.007$) and between pepper–sunflower oil and pepper–MCT oil ($P = 0.004$). There was a significant difference in fat oxidation between the pepper–sunflower oil and pepper–MCT oil ($P = 0.032$). There were no differences in any VAS satiety parameters or gastrointestinal comfort ratings.
Conclusion Adding chilli and MCT to meals increases DIT by over 50 % which over time may cumulate to help induce weight loss and prevent weight gain or regain.

Keywords Chilli · Energy expenditure · Medium-chain triglyceride · Satiety · Diet-induced thermogenesis

Introduction

The prevalence of obesity was estimated at ~23 % among British adults in 2009 [24]. The main reason for such an epidemic is overconsumption of energy-dense foods and decreased energy expenditure (EE) [38]. While reducing energy intake and increasing physical activity are the main approaches to prevent and control obesity in most weight loss programs, there is increasing interest in specific dietary substances that may have beneficial effects on obesity through increased EE [11].

EE is divided into three components: basal metabolic rate (BMR; 50–70 % of total EE), active metabolic rate (30–40 % of total EE) and diet-induced thermogenesis (DIT) [29]. DIT, also recognized as thermic effect of a food, is the increase in energy expenditure above BMR after food ingestion [37]. DIT accounts for about 3–10 % of the total EE depending on the content of the ingested meal [28]. The effects of food components such as caffeine, green tea, chilli and MCT on metabolic rate and thermogenesis have been researched considerably over last 30 years [11]. Herbs and spices have shown positive effects in raising EE in humans [16] and may be one mechanism for weight loss in some but not all individuals

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[4, 8, 32]. The effect of chilli and its active ingredient capsaicin on energy balance, metabolic rate and energy intake in humans has been examined over various time periods from 2 h to 12 weeks, in both overweight and lean subjects [5, 26, 35]. One of the earliest studies showed that the addition of capsaicin and mustard sauce to a breakfast meal increases metabolic rate by 25 % [16]. Findings of several studies have shown that capsaicin and other capsinoid compounds increase EE [14, 20, 43], enhance fat oxidation [6, 20, 30, 43] and increase carbohydrate (CHO) oxidation [21, 43]. Furthermore, it has been shown that capsaicin also improves satiety and decreases energy intake [36, 41, 42].

Medium-chain triglycerides (MCT) are a specific type of dietary triglycerides that are 6–10 carbon atoms in length [5], mainly found in coconut oil and palm kernel oil. It has been shown that MCT consumption increases EE, fat oxidation and satiety and also lowers energy and food intake [10].

A few studies have examined the combined effect of either chilli or MCT with other food components and bioactive ingredients. Reinbach et al. [26] looked at the effects of capsaicin, green tea, CH-19 sweet pepper and a combination thereof. Following a 6-week crossover intervention, decreases in energy intake were observed in the CH-19 sweet pepper and in the combined capsaicin and green tea groups. Belza and Jessen [6] similarly administered supplements containing capsaicin and green tea extract to 19 overweight to obese subjects. The results showed increases in EE of 2 %, as well as increases in fat and CHO oxidation after 7 days of supplement intake. Yoshioka et al. [40] looked at the combined effect of red pepper and caffeine on energy balance. The results showed decreases in energy intake mainly at dinner and breakfast and increases in EE following addition of the red pepper and caffeine combination to a test meal. To date, no researchers have examined the combined effect of MCT and chilli on DIT and satiety.

Both capsaicin and MCT have been shown to reduce adiposity by enhancing energy and lipid metabolism and reducing food intake. The aim of this study is to investigate the effect of a single meal containing combined chilli and MCT oil on EE and perceived hunger compared to meal containing either chilli, MCT or neither.

Methods

Volunteers

Seven healthy volunteers (6f 1m; 25.7 ± 3.6 year; 1.69 ± 0.09 m; 62.5 ± 7.5 kg) were recruited to participate in this study. Ethical approval for the study was obtained from the University Research Ethics Committee at Oxford Brookes University, and all volunteers gave written informed consent to participate. To be included in the study, volunteers had to be between 18 and 45 years, have a stable body mass index (BMI) between 19 and 25 kg/m^2 and have no history of metabolic/genetic diseases, stomach acid problems, reflux in digestive tract or be taking any medications known to interfere with appetite, satiety or food intake. Volunteers were all nonhabitual consumers of capsaicin. Anthropometric measurements were taken during screening. Body weight was recorded to the nearest 0.1 kg using the Tanita BC-418 MA (Tanita UK Limited, Yiewsley, UK) and height to the nearest centimeter using a stadiometer (Seca Ltd, Birmingham, UK). BMI was calculated using the standard formula: weight (kg)/height (m)^2.

Experimental design

Volunteers were tested on four occasions following an overnight fast. On the day prior to testing, volunteers were asked to record their food intake prior to testing and repeat it prior to subsequent tests. Volunteers were also asked to refrain from physical activity the day before each test and on the morning of testing. Subjects were randomly assigned to consume one of the breakfast meals on four different days with a minimum of 4 days between tests.

Energy expenditure measurements

On arrival in the laboratory, volunteers were asked to rest for 30 min in a supine position on a bed before baseline measurements of EE were taken. Resting metabolic rate (RMR) was determined in the morning between 0730 and 0900. RMR was measured at 1-min intervals for 30 min under the ventilated hood indirect calorimetry system (Deltatrac™ II Metabolic Monitor, Datex-Ohmeda Inc., Finland). The analyzer was calibrated on each test day with standardized gases containing 5 % CO_2 and 95 % O_2.

DIT was determined after the breakfast meal for 15 min in every 30 min for 360 min after breakfast ingestion [25]. The first 5 min of every 15 min time period was discarded to allow for stabilization within the Deltatrac hood, and the average of the remaining 10 min was used. This time period was recommended to be appropriate to measure the thermic effect of foods [25]. Energy expenditure and fat and CHO oxidation were calculated using the equations of Lusk [22].

Test meal

After measurements of RMR were taken, subjects consumed the breakfast test meal within a 15-min period. The meal used to assess DIT was a fried breakfast, consisting of an egg omelet, tomato, mushroom, sausage, bacon, toast and orange juice (Table 1). The cooked breakfast was prepared with chilli and MCT oil, chilli and sunflower oil, bell pepper and sunflower or bell pepper and MCT oil added to the omelet. Glucose was added to chopped bell pepper to give it a similar macronutrient and energy cost as the chilli mix. The chilli mix consisted of 60 % chilli (cayenne, habanero). The capsaicin content of the chilli blend was estimated about 2,000 ppm capsaicin (based on information provided by the manufacturers). According to this, the 30 g chilli blend added to breakfast meal was comparable to the amount of chilli used (30 g) in earlier studies to assess the effect of chilli on metabolic parameters [2, 3]. Twenty grams of MCT oil was used based on the amounts previously found to have an increase in DIT [10]. Due to the lower energy density of long-chain triglycerides, only 18.4 g of sunflower oil was used to match the energy content of the meals.

Satiety and gastrointestinal comfort

One hundred–millimeter continuous-line visual analogue scales (VAS) were utilized to measure subjective feelings of hunger, fullness, desire to eat and prospective food consumption. The volunteers provided VAS data at baseline (0 min) and at 30, 60, 90, 120, 150, 180, 210 and 240 min after the commencement of eating the test food. The specific questions asked were the following: "How hungry do you feel?" "How full do you feel?" "How strong is your desire to eat?" "How much food do you think you can eat?" Gastrointestinal comfort was measured using a 10-point scale to assess complaints of nausea, belching, bloatedness, headache and dizziness or gastrointestinal cramping at baseline (0 min) and at 30, 60, 90, 120, 150, 180, 210 and 240 min. The VAS ratings were quantified by measuring in millimeters the distance between the left end of the scale and the point marked by the participant. The "change in the subjective feeling" was calculated by computing the difference between the response at a time point and the baseline value (at 0 min). Using the "change in subjective feeling" data, temporal curves were constructed for each of the four VAS questions for the testing time. The incremental area under the curve (IAUC) was then calculated using the trapezoidal rule for each of these curves.

Table 1 Energy content and macronutrient composition of breakfast meal

Test meal	Quantity (g)	Energy (kJ)	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)
Free range medium eggs[a]	50.0	346	83.0	6.9	5.8	0.9
Tomato[a]	25.0	19	4.5	0.2	0.1	0.8
Closed cup mushrooms[a]	25.0	14	3.3	0.5	0.1	0.1
Pork sausages[a]	50.5	463	112.5	7.0	6.7	5.6
Unsmoked back bacon rashers[a]	17.5	230	57.5	3.7	4.5	0
White bread[b]	35.0	352	83.0	3.0	0.6	17.4
MCT oil[c]	20.0	166	39.7		20.0	
Sunflower oil[a]	18.4	166	39.7		18.4	
Hot chilli spice blend[d]	30.0	176	42.0	0.3	0.1	8.6
Bell pepper[a] and glucose[e]	18.0	176	42.0	0.2	0.1	10.1
	8.7					
Pure orange juice[a]	100 ml	99	23.5	0.3		5.3
Water	100 ml					
Total						
Percentage				19.9	44.6	35.5
Chilli + MCT oil		1,863	448.9	21.7	37.9	38.6
Chilli + sunflower oil		1,863	448.9	21.7	36.3	38.6
Pepper + sunflower oil		1,863	448.9	21.6	36.3	40.1
Pepper + MCT oil		1,863	448.9	21.6	37.9	40.1

[a] Tesco Cheshunt, Hertfordshire, UK

[b] Kingsmill Maidenhead UK

[c] Trek nutrition, Trek Nutrition, London, UK

[d] Gourmet garden, Northampton, UK

[e] Lloyds pharmacy Ltd, Coventry, UK

Data and statistical analysis

A priori power calculation predicted that a sample size of seven volunteers would be sufficient to achieve a power of 0.9 with SD of 13 kJ and change in mean DIT of 50 kJ [40]. Statistical analysis was conducted using SPSS version 19 (SPSS Inc., Chicago, Illinois). A Kolmogorov–Smirnov test indicated that the data were normally distributed. Data are presented as mean ± SD. Differences in the average fat oxidation, and total energy expenditure (AUC) as well as satiety IAUCs and average gastrointestinal comfort were compared using one-way RM-ANOVA ($P \leq 0.05$). Comparisons between meals were done by examining contrasts within the ANOVA. Comparisons of energy expenditure, fat oxidation and satiety across time were compared using two-way RM-ANOVA with two within-subject factors—time and meal.

Results

Energy expenditure

The energy expenditure increased postprandially following all four breakfasts reaching a peak in the chilli–sunflower oil and pepper–sunflower oil at 1 h and at 2 h in the chilli–MCT oil and pepper–MCT oil, respectively. The rate of postprandial energy expenditure changed both over time ($P < 0.001$) and between meals ($P < 0.001$; Fig. 1).

There were significant differences in total DIT and percentage DIT between the different breakfast meals ($P = 0.003$, Table 2). The predominant differences existed between the chilli–MCT oil and chilli–sunflower oil ($P = 0.013$), between chilli–MCT oil and pepper–sunflower oil ($P = 0.007$) and between pepper–sunflower oil and pepper–MCT oil ($P = 0.004$). Chilli–MCT had the highest EE, and pepper–sunflower oil had the lowest. It was noted that the increased energy expenditure occurred between 2 and 6 h postprandially; analysis of these data alone substantiated the results above.

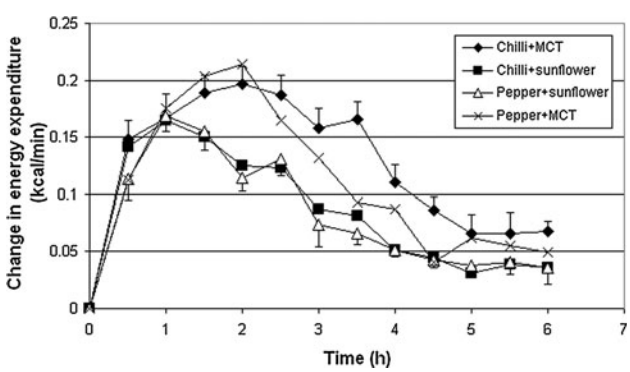

Fig. 1 Postprandial change in energy expenditure following the breakfast test meals containing chilli and medium-chain triglyceride (MCT) oil, chilli and sunflower oil, bell pepper and sunflower oil or bell pepper and MCT oil. SD for the middle values (chilli–sunflower oil and pepper–MCT oil) was similar to the other two meals and omitted to improve clarity

Fat oxidation

There was no significant difference in overall average rate of fat oxidation between the different meals ($P = 0.424$, Table 2); however, there was a significance between the pepper–sunflower oil and pepper–MCT oil ($P = 0.032$; Fig. 2).

The rate of fat oxidation did not differ between meals but did differ across time, and there was a significant meal–time interaction ($P < 0.001$). The rate of fat oxidation initially increased postprandially following both chilli–MCT oil and pepper–MCT oil but not the pepper–sunflower oil or chilli–sunflower oil where it decreased for the first hour postprandially and then began to increase gradually thereafter.

Carbohydrate oxidation

There was no significant difference in overall average rate of CHO oxidation between the different meals ($P = 0.239$, Table 2). The rate of CHO oxidation did not differ between meals but did differ across time, and there was a significant meal–time interaction ($P < 0.001$). The rate of CHO oxidation initially increased postprandially following all four meals with the elevations being greater in the two groups without the MCT oil (Fig. 3).

Satiety

Satiety increased immediately postprandially for all satiety parameters such as hunger, fullness, desire to eat and prospective consumption and then gradually reduced over the testing time ($P < 0.05$). There were no differences in any of the VAS satiety parameters of hunger, fullness, desire to eat and prospective food consumption between the four test meals ($P > 0.05$; Table 3).

Gastrointestinal comfort

All ratings remained close to baseline levels throughout the test, with feelings of bloatedness and belching remaining at the lowest possible value for all volunteers for all tests. Feelings of cramping, nausea and headache were increased on average in all meals, but there were no significant differences in any of the ratings of gastrointestinal comfort ($P > 0.05$; Table 4).

Table 2 Energy expenditure and fat oxidation following each of the breakfast meals

	Chilli–MCT oil	Chilli–sunflower oil	Pepper–sunflower oil	Pepper–MCT oil
DIT (% of total test meal energy)*	10.7 ± 2.6	7.2 ± 2.6	7.0 ± 2.5	9.4 ± 2.7
Postprandial energy expenditure (kcal)*	48.2 ± 11.6	32.2 ± 11.8	31.4 ± 11.3	42.2 ± 12.09
2–6 h postprandial energy expenditure (kcal)*	26.2 ± 8.7	14.5 ± 7.4	14.1 ± 8.3	20.1 ± 6.4
Average fat oxidation (g/min)	0.076 ± 0.005	0.069 ± 0.010	0.054 ± 0.009	0.064 ± 0.007
Average CHO oxidation (g/min)	0.093 ± 0.055	0.122 ± 0.027	0.135 ± 0.026	0.109 ± 0.014

* $P < 0.05$

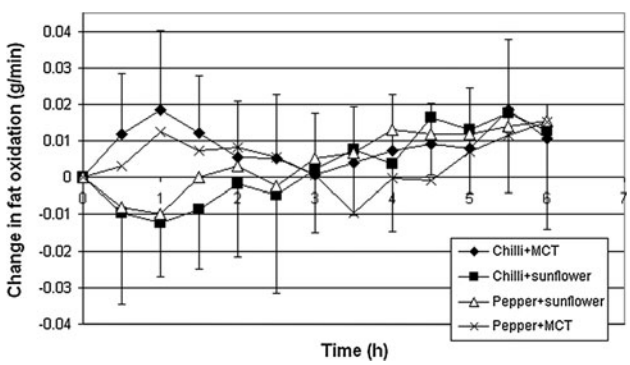

Fig. 2 Postprandial change in fat oxidation following the breakfast test meals containing chilli and medium-chain triglyceride (MCT) oil, chilli and sunflower oil, bell pepper and sunflower oil or bell pepper and MCT oil. SD for the middle values (pepper–sunflower oil and pepper–MCT oil) was similar to the other two meals and omitted to improve clarity

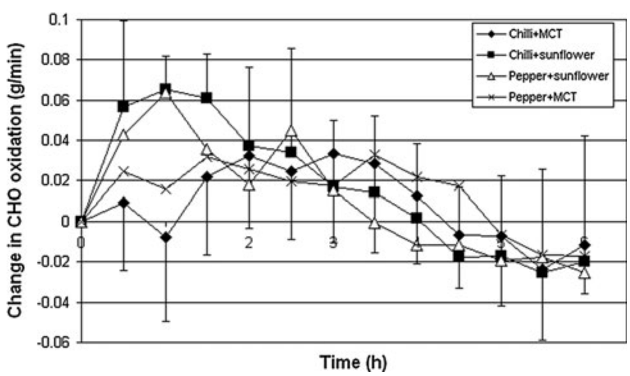

Fig. 3 Postprandial change in carbohydrate (CHO) oxidation following the breakfast test meals containing chilli and medium-chain triglyceride (MCT) oil, chilli and sunflower oil, bell pepper and sunflower oil or bell pepper and MCT oil. SD for the middle values (pepper–sunflower oil and pepper–MCT oil) was similar to the other two meals and omitted to improve clarity

Discussion

The findings of the current study indicate that combined chilli–MCT oil feeding had a cumulative effect on DIT to increase it by 51 % compared to a control of pepper–sunflower oil, from 7.0 to 10.6 % of the test meal energy. The chilli–MCT oil combination caused the greatest increase in DIT, and as expected, the control of the pepper–sunflower oil had the lowest DIT. It was anticipated that the chilli–MCT oil would have the highest DIT due to the fact that both chilli and MCT when fed individually are known to increase DIT and do this via different metabolic pathways. In the current study, the hypothesized outcome occurred; however, this was primarily done to the MCT rather than the chilli. Capsaicin, the active ingredient of chilli, is believed to increase EE by activating the sympathetic nerves via specific receptors that stimulates the secretion of noradrenalin into the synaptic cleft, where the noradrenalin interacts with the adrenergic receptors [9, 19, 35]. MCT similarly has been shown to mediate its affects at least in part through activation of the sympathetic nervous system as evidenced through increases in urinary noradrenalin excretion in humans [12]. However, MCT also increases EE as they are transported directly in the portal venous system, as opposed to being transported as chylomicrons in the lymphatic system like long-chain triglycerides (LCT) [7]. MCT bypass peripheral tissues, such as adipose tissue, which makes them less susceptible to the actions of hormone-sensitive lipase and to deposition into adipose tissue stores [5]. This makes them more preferentially utilized as they are a readily available fuel source. In addition, medium-chain fatty acids can cross the mitochondrial membrane of the liver and muscle independently of the acylcarnitine transfer system. For these reasons, MCT are a much more readily available energy source than long-chain triglycerides [39].

It can be seen that the MCT had the greatest effect on DIT. The amount of MCT used in the current study was 20 g. Most MCT–DIT studies have used 30 g or greater MCT oil and found increases above baseline. Scalfi et al. [27] found increases in daily EE of approximately 119.7 ± 33.9 and 144.7 ± 48.8 kJ/6 h in lean and the obese subjects using 30 g MCT, and Flatt et al. [13] found increase of 105 ± 13 kcal/9 using ~42 g MCT. Other studies that used as low as 5 g of MCT have also been shown to increase postprandial thermogenesis [18]. Although a lower amount of MCT was used in the current study, compared to many of those previously completed, it still had a DIT of 42.2 kcal above baseline (pepper–MCT oil) over 5.5 h. For the chilli meals, similar or greater

Table 3 Satiety from visual analogue scales for the breakfast test meals containing chilli and medium-chain triglyceride (MCT) oil, chilli and sunflower oil, bell pepper and sunflower oil or bell pepper and MCT oil

(mm·min)	Chilli–MCT oil	Chilli–sunflower oil	Pepper–sunflower oil	Pepper–MCT oil
Hunger	12,106 ± 6,846	11,766 ± 6,763	14,871 ± 5,005	14,609 ± 4,651
Fullness	12,467 ± 4,405	10,472 ± 5,061	10,474 ± 3,746	13,135 ± 4,603
Desire to eat	12,473 ± 6,222	13,025 ± 4,613	13,726 ± 4,944	15,329 ± 4,091
Prospective consumption	10,598 ± 4,987	9,519 ± 5,543	11,183 ± 4,388	11,739 ± 4,331

Table 4 Illness ratings following the breakfast test meals containing chilli and medium-chain triglyceride (MCT) oil, chilli and sunflower oil, bell pepper and sunflower or bell pepper and MCT oil

	Chilli–MCT oil	Chilli–sunflower oil	Pepper–sunflower oil	Pepper–MCT oil
Nausea	1.11 ± 0.18	1.00 ± 0.00	1.02 ± 0.06	1.13 ± 0.23
Belching	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00
Bloatedness	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	1.02 ± 0.06
Headache	1.24 ± 0.33	1.04 ± 1.00	1.07 ± 0.08	1.19 ± 0.33
Cramping	1.35 ± 0.88	1.25 ± 0.66	1.20 ± 0.54	1.10 ± 0.25

amounts were used in the previous studies [1–3, 16, 40] compared to the current study. However, the increase in DIT was not as obvious in the current study as was also found in Ahuja et al. [3]. This may have been due to the large nature of the test meal (448.9 kcal) diluting the capsicum or that many of the more recent previous studies have given it in capsule form [5, 26]. Fat oxidation has been shown to be increased following MCT feeding [31] and chilli feeding [43]. The current study showed that fat oxidation was initially increased in the meals containing MCT oil, primarily the chilli–MCT oil meal, but not in those containing sunflower oil which only started to increase after 1 h postprandially. Similar findings were presented in Yosioka et al. [40] where lipid oxidation was decreased after lunch but was increased later during sleeping. In the current study, this may have been due to the long-chain triglyceride in the sunflower oil delaying gastric emptying, meaning that the chilli would not have been absorbed until later in the test session [23].

No differences were seen in the VAS measurements for satiety. The graphs indicate that there may be a slight trend toward greater satiety with the chilli–MCT oil combination; however, this was not confirmed and may need a more rigorous methodology than VAS. VAS have been shown to correlate with but not reliably predict energy intake [34]. *Ad libitum* intake may need to be assessed to thoroughly answer this question of whether combined intake of chilli and MCT can have cumulative effects on food intake as demonstrated by the components individually [33, 36]. MCT have been shown to cause gastrointestinal discomfort at high doses (approximately 85 g/h) [15, 17]; hence, a lower amount was selected in this instance, and the results show that the volunteers did not suffer from any discomfort that would have confounded the results of this study.

Obesity generally occurs as a result of increased energy intake and decreased EE and is a major contributor to the development and progression of disorders such as insulin resistance, hyperinsulinemia, type 2 diabetes and cardiovascular disease. By increasing EE, we can reduce the amount of excess energy stored as adipose tissue in the body. One potential mechanism for this is through increasing the intake of food that promotes EE. The present study aimed to examine the effects of combined chilli and MCT on EE and satiety in healthy individuals. Adding chilli and MCT to meals increases the DIT response by over 50 % and over larger time periods may cumulate to help to induce weight loss and prevent weight gain or regain. Through their separate increases in EE and reductions in food intake, combined chilli and MCT feeding may pose as a potential mechanism for weight loss.

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