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Original Article

Effects of capsaicin, green tea and CH-19 sweet pepper on appetite and energy intake in humans in negative and positive energy balance

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SUMMARY

Background & aims: Bioactive ingredients have been shown to reduce appetite and energy intake. The magnitude of these effects might depend on energy balance why it was investigated how capsaicin, green tea, CH-19 sweet pepper as well as green tea and capsaicin affect appetite and energy intake during respectively negative and positive energy balance.

Methods: 27 subjects were randomized to three weeks of negative and three weeks of positive energy balance during which capsaicin, green tea, CH-19 sweet pepper, capsaicin + green tea or placebo was ingested on ten separate test days while the effects on appetite, energy intake, body weight and heart rate were assessed.

Results: CH-19 sweet pepper and a combination of capsaicin and green tea reduced energy intake during positive energy balance. Capsaicin and green tea suppressed hunger and increased satiety more during negative than during positive energy balance.

Conclusions: Bioactive ingredients had energy intake reducing effects when used in combinations and in positive energy balance. Energy balance did not affect possible treatment induced energy intake, but did affect appetite by supporting negative energy balance. Bioactive ingredients may therefore be helpful in reducing energy intake and might support weight loss periods by relatively sustaining satiety and suppressing hunger.

1. Introduction

Although weight loss approaches using green tea or capsaicin have recently gained more attention due to the beneficial effect on the targets in body weight regulation, namely satiety, energy-metabolism, substrate oxidation and body composition[1] little attention has been paid to the effects on appetite and energy intake.[2,3] Increased activity of the sympathetic nervous system (SNS) after ingestion of capsaicin suggests that the reduction in energy intake could be due to the anorectic effect of catecholamines.[3] Largest reduction in energy intake was observed when capsaicin was administered orally compared to gastrointestinal stimulation[2,4] suggesting that sensory stimulation by capsaicin is of importance to the total response.[2] Since using capsaicin over a longer period of time is hardly possible and results in bad compliance,[2] the non-pungent CH-19 sweet pepper (Capsicum annuum L.) could be an attractive alternative to capsaicin. Not only a single dose of CH-19 sweet pepper increased body temperature and oxygen consumption,[5] but also repeated CH-19 sweet pepper intake for two weeks reduced body weight and enhanced fat oxidation by increasing the SNS in humans.[6] However little is known about how CH-19 sweet peppers affect energy intake and appetite.

Two active compounds, catechins and caffeine, contribute to the beneficial metabolic effects of green tea.[7–11] Few studies have looked at the effect of green tea on energy intake and appetite however Kao et al.[12] showed that epigallocatechin-3-gallate (EGCG) from green tea reduced food intake and body weight in rats within 7 days and that the effects of EGCG were dose-dependent.

In both animals[13,14] and humans[15–18] positive energy balance increases activity of the SNS supporting that SNS has a role in counteracting positive energy balance to maintain energy balance.[15] Taking these findings into account we hypothesized that possible effects of hot spices and green tea on energy intake might depend on energy balance.

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The aim of this study was therefore to investigate how one day exposure to capsaicin, green tea, CH-19 sweet pepper or capsaicin and green tea affect appetite and energy intake during respectively negative and positive energy balance. In order to find evidence for this hypothesis; the study was conducted with normal weight subjects.

2. Materials and methods

2.1. Subjects

27 healthy subjects (10 men and 17 women) with a mean age of 26.9 ± 6.3 years (mean ± SD), mean BMI of 22.2 ± 2.7 kg/m^2 and without food allergies were recruited in and around Maastricht University and hospital. The study was approved by the medical ethics committee of the Maastricht University Hospital and all subjects gave informed consent to the work prior to the start. A power calculation with an effect size of 10% and a 90% power revealed that 24 subjects would be needed to detect 10 mm difference in the Appetite VAS.[19] With an expected drop out of 10% final sample size was determined to be 27 subjects. The height and weight of the participants were measured to calculate BMI and attitude towards eating: cognitive restrained and unrestrained eating behaviour (F1), emotional eating and disinhibition (F2) and subjective feeling of hunger (F3) were assessed by using a validated Dutch translation of 'The Three-Factor Eating Questionnaire'.[20] All subjects participated in the study for six weeks and were randomly assigned to three weeks of positive energy balance and three weeks of negative energy balance.

2.2. Procedure

Subjects participated in a six weeks crossover meal study, where they were randomly assigned to two conditions, three weeks of negative energy balance and three weeks of positive energy balance (Fig. 1). Subjects came fasting in the morning at university and were served standardized breakfast and lunch during weekdays whereas subjects prepared their usual food in the evenings and weekends at home. Five test days in which subjects consumed the treatments (capsaicin, green tea, CH-19 sweet pepper, capsaicin + green tea or placebo) with three daily meals (standardized breakfast, standardized lunch, ad libitum dinner) were performed during each of the two conditions. Serving orders of the treatments were randomized and balanced by means of Hall test calculations.[21] On test days participants wore a heart rate monitor (Polar RS400, Finland/USA) all days; they were weighed before breakfast, lunch and dinner on a digital scale accurate to 0.02 g (Chyo-MW-150 K, Japan) and scored appetite on 100 mm visual analogue scales (VAS) eight times per test day. No test meals took place during one week after the shift of energy balance conditions.

2.3. Energy balance

Subjects were fed to positive energy balance by receiving 20% of their individually calculated daily energy requirement for breakfast and 40% of their total daily energy requirement for lunch. When subjects were fed to negative energy balance, 10% of their individually calculated total daily energy requirement was provided for breakfast and 15% of their total daily energy requirement was provided for lunch. Subjects had to consume all the food provided. Normally, 15% of total energy requirement is given for breakfast and 30–35% for lunch, so with these provisions it was feasible to reach positive and negative energy balance during each condition. Estimates of subject specific daily energy intake were made by calculating basal metabolic rate (BMR) from the Harris–Benedict equation[22] and multiplying BMR with a personal physical activity index (PAI) of 1.5–1.9, based upon the outcome of the Baecke questionnaire.[23]

The standardized breakfast consisted of orange juice, low fat strawberry quark and typical Dutch spicy breakfast cake (Table 1). At lunch participants got a baguette with cheese and ham, a baguette with apple syrup, a raisin roll and an apple during the negative energy balance condition. During the positive energy balance condition participants got larger baguettes, more raisin rolls, an apple and a pear. The energy content of the meals was calculated from the nutrition information on the food items or from the standard Dutch NEVO food composition table.[24] Positive or negative energy balance was confirmed by measuring the ultimate weight changes after finishing each energy balance condition.

2.4. Test days

Each subject participated in ten test days during the intervention period where the treatments, capsaicin, green tea, CH-19 sweet pepper, capsaicin + green tea and placebo were ingested with the subject specific breakfast and lunch in the ongoing energy balance

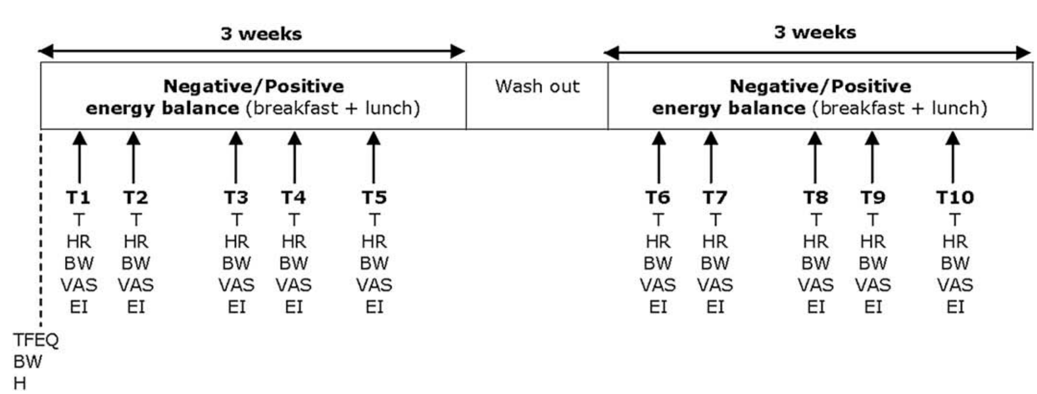

Fig. 1. Schematic illustration of the study design and protocol. Positive energy balance provided 20% of daily energy need for breakfast and 40% for lunch whereas negative energy balance provided subjects with respectively 10% and 15% of individual energy need for breakfast and lunch. The treatments (T) (capsaicin, green tea, CH-19 sweet pepper, capsaicin and green tea or placebo) were provided with three daily meals on each of the 10 test days (T1–T10). The following parameters were measured on every test day: BW: Body weight (kg) (before each meal); H: Height (m); HR: Heart rate (beats/min) (throughout the day); VAS: visual analogue scales on the appetite (8 times per day), liking (before and after each meal), desire to eat sour, sweet, fat, bitter, salty and hot stimuli (8 times per day); EI: ad libitum energy intake (kJ and g) during dinner. TFEQ: The Three-Factor Eating Questionnaire was filled before the first test day.

Table 1
Composition, serving size (g) and energy content (kJ) of the meals based on an energy requirement of 10 MJ per day.

	Food	Negative energy balance (10% Breakfast 15% Lunch)			Positive energy balance (20% Breakfast 40% Lunch)		
		g	Kj	Energy content	g	Kj	Energy content
Breakfast	Orange Juice	163	260.8	Protein 17%	333	532.8	Protein 17%
	Spiced breakfast cake	39	503.1	Fat 3.5%	76	980.4	Fat 3.5%
	quark yogurt	163	244.5	Carbohydrates 79.5%	333	499.5	Carbohydrates 79.5%
	Total	365	1008.4		742	2012.7	
Lunch	Multigrain brown baguette	68	639	Protein 15%	201	1889.4	Protein 17%
	Ham	6	28.8	Fat 8%	26	124.8	Fat 10.5%
	Cheese	6	94.2	Carbohydrates 70%	26	408.2	Carbohydrates
	Apple syrup	2	23.4		16	187.2	65.5%
	Raisin roll	38.6	413.0		77.2	826.0	
	Apple	150	310.5		150	310.5	
	Pear	–	–		130	261.3	
	Total	270.6	1509.1		626.2	4007.44	
Ad libitum dinner	Lasagne	900–1800	4500–9000		900–1800	4500–9000	
	Salad with oil/vinegar	310	247		310	247	

condition, and with an ad libitum dinner. Subject had two test days each week on non-consecutive days, and one week without test days after energy balance conditions were shifted, to avoid carry-over effects from one treatment to the other. The test meals were consumed individually in dining rooms at the university.

The following 5 different treatments were applied randomly: 1) capsaicin capsules (510 mg cayenne, 40,000 Scoville heat units (SHU)), 2) 3.5 dl green tea drink (598.5 mg catechins, 77 mg caffeine), 3) CH-19 sweet pepper capsules (2.3 mg capsiate, Ajinomoto, Japan), 4) 3.5 dl green tea drink (598.5 mg catechins, 77 mg caffeine) + capsaicin capsules (40,000 SHU) and 5) placebo capsules with every meal. In addition to capsules (capsaicin, CH-19 sweet pepper and placebo) subjects also received 3.5 dl of water to assure that the same amount of liquid was consumed on every test day. Thus the total amount of active compound consumed on a test day was 7 mg capsiate from CH-19 sweet pepper. The green tea was imported from Kao, Japan and contained the active compounds catechins (gallocatechin (GC), epigallocatechin (EGC), catechin (C), epicatechin (EG), epigallocatechine gallate (EGCG), gallocatechine gallate (GCG), epicatechine gallate (ECG), catechine gallate (CG)) and caffeine providing a total of 1795.5 mg catechins and 231 mg caffeine on every test day. In the following, the mixture of tea catechins and caffeine is referred to as 'green tea'.

For the ad libitum dinner meal, participants received an average 1.5 kg of Italian lasagne and 300 g of a mixed salad with 10 g of an oil/vinegar dressing (Table 1). Serving size was as such that leftovers always remained on the plate. Total ad libitum food intake was measured by weighing the food before and after serving.

2.5. Ratings of appetite, liking and food desires with the test meals

All ratings were scored on 100 mm VAS. Appetite ratings were made eight times a day, before and after every meal, in between breakfast and lunch and between lunch and dinner. Appetite was scored as *hunger* ranging from 'not at all hungry' at 0 till 'very hungry' at 100 mm, *desire to eat* from 'very weak' till 'very strong', *prospective food consumption* from 'nothing at all' till 'a very large portion', *fullness* from 'not at all full' till 'very full' and finally *satiety* was scored from 'not at all satiated' till 'very satiated'. Liking was anchored with 'not at all' and 'very much' and scored before and after breakfast, lunch and dinner. Furthermore participants scored their desires to eat sour, sweet, fat, bitter, salty and hot stimuli before and after every meal, in between breakfast and lunch and between lunch and dinner ranging from 'not at all' to 'very much'.

2.6. Data analysis

All test parameters were presented as the mean ± standard error (SE). Results were expressed in mean values or Δ values (treatment minus placebo).

The repeated measures of weight (before breakfast, lunch and dinner) were analyzed by linear mixed models in SAS (SAS Institute, Inc., Cary, NC, USA) and evaluated for significant effects of time of the day as well as condition (energy balances). A mixed repeated analysis was made on appetite measures (random effect: subject; fixed factor: treatment, gender, time and condition; covariates: BMI, age, baseline appetite, temperature of the test day and three-factor eating scores (factor 1, factor 2 and factor 3)) as well as for desires to eat sour, sweet, fatty, bitter, salty and hot scores and liking scores. In addition mixed models were used to analyze the ad libitum energy intake (kJ and g) (random effects: test day, subjects; fixed factor: gender, time of dinner, condition and treatment; covariates: BMI, age, temperature, liking before the meal, hunger and factor 1, factor 2 and factor 3) and the heart rate measures. Significance was set at a p-value <0.05. When statistically significant differences were detected, a post hoc pairwise comparison across treatments and conditions was performed by using Tukey–Kramer's test and the corresponding adjusted p-value (adj p) was found.

3. Results

Subject characteristics are summarized in Table 2

3.1.1. Positive and negative energy balance

In general, differences between positive and negative energy balances were observed with respect to body weight, heart rate, ad lib energy intake, appetite and liking of the food as subjects differed from their 'normal profiles' in these parameters. An example is given in Fig. 2 showing how satiety during negative and positive energy balance and during 'a normal satiety profile[25]' differs through and after the lunch meal.

Body weight changes during each of the energy balance conditions (Δ Body weight) were calculated by subtracting the baseline body weight, measured respectively before the negative energy balance condition and before the positive energy balance condition, from the body weights measured on the test days. A significant condition × test day interaction ($p < 0.01$) revealed that subjects gained weight during the positive energy balance and lost weight during the negative energy balance condition. Body weight was increased by 0.50 ± 0.2 kg ($p < 0.05$) during positive energy

Table 2
Subject characteristics (number or mean ± standard deviation (SD)).

	Women	Men	All
N	17	10	27
Age (years)	23.6 ± 2.6	32.5 ± 7.0	26.9 ± 6.3
Body weight (kg)	62.4 ± 6.6	75.8 ± 15.0	67.3 ± 12.2
BMI (kg/m^2)	21.7 ± 1.7	23.0 ± 3.8	22.2 ± 2.7
PAI	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1
ADMR (MJ/24 h)	11.3 ± 1.1	12.9 ± 1.9	11.9 ± 1.6
Restraint (Factor 1)	8.5 ± 4.5	5.2 ± 3.9	7.3 ± 4.5
Disinhibition (Factor 2)	5.9 ± 3.4	4.4 ± 2.9	5.4 ± 3.2
Hunger (Factor 3)	5.8 ± 2.8	3.9 ± 3.6	5.1 ± 3.2

PAI: physical activity index; ADMR: average daily metabolic rate; Restraint, disinhibition, hunger are scores of the Three-factor eating questionnaire by Stunkard and Messick.[20]

balance whereas body weight was decreased by 0.44 ± 0.2 kg ($p < 0.05$) during negative energy balance, suggesting that positive and negative energy balances were achieved.

Similarly, pairwise comparisons of the effect of conditions showed that heart rate was significantly higher during positive energy balance (4.1 ± 1.4 beats/min ($p < 0.01$)) than negative energy balance when comparing heart rates measured on the placebo test day.

Furthermore achievement of negative and positive energy balance was confirmed by the energy intake as well as by the appetite measures. Subjects ate significantly more of the ad libitum dinner during the negative than during the positive energy balance ($p < 0.01$) (Fig. 3) and positive energy balance led to significantly higher sensation of fullness and satiety as well as significantly lower feelings of hunger, desire to eat and prospective food consumption ($p < 0.0001$; data not shown).

Also desire for eating sour, sweet, fatty, bitter, salty and hot foods as well as liking of the meals was significantly higher during the negative energy balance than during the positive energy balance ($p < 0.01$), however liking over a meal was significantly decreased after breakfast, lunch and dinner for both negative and positive energy balance ($p < 0.05$).

3.1.2. Effects of capsaicin, green tea, CH-19 sweet pepper and capsaicin + green tea on energy intake, appetite, liking, and heart rate

To test if the effects of treatments differ between positive and negative energy balance, pairwise comparison between treatments

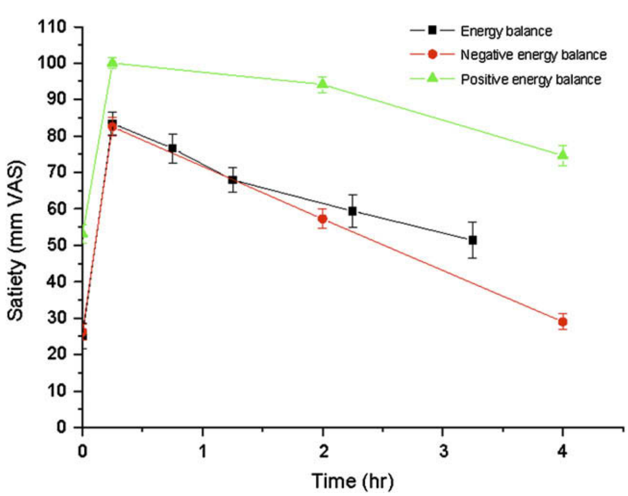

Fig. 2. Satiety ratings measured with 100 mm VAS after consuming lunch in respectively negative and positive energy balance. 'The normal satiety profile' for subjects in energy balance is shown for comparison.

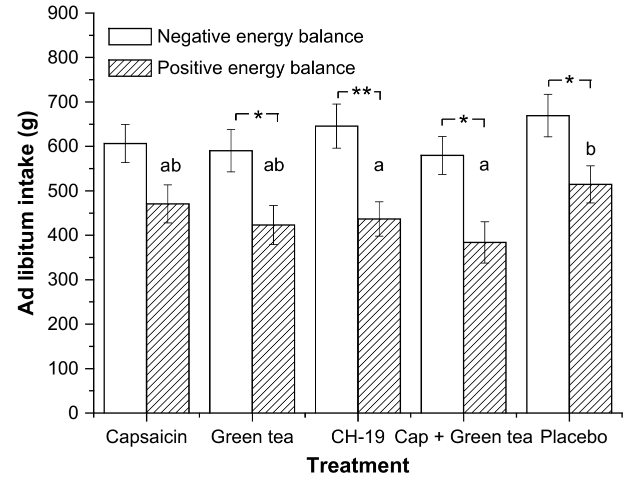

Fig. 3. ad lib energy intake (Mean values ± SE) for each of the five treatments during negative and positive energy balance. Notation of significances *(5%), **(1%) and ***(0.1%) specifies significant effects of energy balance on ad lib energy intake for each treatment. Significant effects ($p < 0.05$) of treatments on ad lib intake during positive energy balance are indicated with different letters (e.g. a is sign. different from b).

and placebo was made for the two conditions, positive and negative energy balance (Table 3). No significant interactions affecting energy intake were found. CH-19 sweet pepper, and capsaicin + green tea significantly decreased energy intake during positive energy balance (Table 3, Fig. 3).

For appetite significant interaction between treatment and condition indicated that treatment effects depend on energy balance and especially the combination of green tea + capsaicin influenced appetite with stronger effect in negative than in positive energy balance (Table 3).

Furthermore, incidentally differences in appetite were shown, yet no convincing multiple significances were present.

Furthermore the combination of capsaicin and green tea significantly reduced liking over the meals ($p < 0.0001$, adj. $p < 0.0001$) when compared to placebo whereas these ingredients individually did not affect liking over the meals suggesting that combining bioactive ingredients contributes to a stronger sensory specific satiety (SSS) over a meal.

A significant treatment × desire interaction ($p < 0.0001$) revealed that capsaicin, green tea and the combination of capsaicin and green tea significantly reduced desire to eat fatty, salty and hot ($p < 0.05$), capsaicin additionally reduced desire to eat sour ($p < 0.05$) and capsaicin + green tea reduced desire to eat bitter ($p < 0.05$) during both positive and negative energy balance whereas CH-19 sweet pepper did not affect any desires. No treatment effects of capsaicin, green tea, CH-19 sweet pepper and capsaicin + green tea were shown on average daily heart rate when compared to placebo.

4. Discussion

The present study did not support our hypothesis that positive or negative energy balance would affect possible treatment effects of bioactive ingredients, namely capsaicin, green tea, CH-19 sweet pepper, and a combination of green tea and capsaicin on energy intake.

Negative or positive energy balance was confirmed by respectively losing or gaining of body weight as well as by lower heart rate, higher *ad lib* energy intake, greater appetite and liking of the meals during negative energy balance when compared to positive energy balance.

Table 3
Estimated values of the treatment effects (treatment − placebo) calculated from the statistical model (Differences of LSMeans ± SE).

	Energy balance	Ad libitum intake (kJ)	*p*-value/Adj *p*-value*	Hunger (mm)	*p*-/Adj *p*-value*	Desire to eat (mm)	*p*-value/Adj *p*-value*	Full (mm)	*p*-value/Adj *p*-value*	Satiety (mm)	*p*-value/Adj *p*-value*	Av. heart rate (beats/min)	*p*-value*
Capsaicin	Neg.	−304.4 ± 162.7	ns	−3.4 ± 2.3	ns	−1.5 ± 2.4	ns	7.0 ± 2.6	**0.007** ns	5.4 ± 2.7	**0.043**	−0.3 ± 1.4	ns
	Pos.	−181.6 ± 161.5	ns	−5.2 ± 2.3	**0.023** ns	−4.7 ± 2.4	ns	2.0 ± 2.6	ns	3.3 ± 2.6	ns	−1.3 ± 1.4	ns
Green tea	Neg.	−277.6 ± 162.8	ns	1.8 ± 2.3	ns	1.2 ± 2.4	ns	5.8 ± 2.6	**0.028** ns	3.9 ± 2.7	ns	0 ± 1.4	ns
	Pos.	−310.0 ± 163.1	ns	−4.9 ± 2.3	**0.035** ns	−4.5 ± 2.4	ns	2.5 ± 2.6	ns	4.8 ± 2.7	ns	−0.9 ± 1.4	ns
CH-19 sweet pepper	Neg.	−215.87 ± 164.8	ns	3.8 ± 2.3	ns	2.9 ± 2.4	ns	1.2 ± 2.6	ns	−0.3 ± 2.6	ns	−1.4 ± 1.4	ns
	Pos.	−360.34 ± 162.2	**0.027** 0.445	−3.3 ± 2.3	ns	−2.7 ± 2.4	ns	0.1 ± 2.6	ns	0.9 ± 2.7	ns	−2.3 ± 1.4	ns
Capsaicin + green tea	Neg.	−307.42 ± 162.4	Ns	−8.1 ± 2.3	**<0.001** **0.018**	−9.1 ± 2.4	**<0.001** **0.007**	12.7 ± 2.6	**<0.001** **<0.001**	13.4 ± 2.6	**<0.001** **<0.001**	−0.6 ± 1.4	ns
	Pos.	−370.33 ± 161.8	**0.023** 0.400	−5.5 ± 2.3	**0.018** ns	−5.1 ± 2.4	**0.036** ns	5.5 ± 2.6	**0.035** ns	5.7 ± 2.7	**0.033** 0.499	−1.4 ± 1.4	ns

**p*-values indicate significant difference between the treatment and placebo for respectively negative energy balance and positive energy balance. mm = mm VAS. LSMeans, Least Squared Means; Differences of LSMeans are calculated as LSMeans for Treatments minus LSMeans for placebo. Thus negative values for differences in LSMeans indicate that the treatment has reducing effect whereas positive values in the table indicate enhancing effect of the treatment when compared to placebo.

Interaction between energy balance and treatment revealed that hunger and desire to eat were more reduced, while fullness and satiety were more increased, during the capsaicin + green tea treatment following negative energy balance than positive energy balance. It seems reasonable that the strongest treatment, capsaicin + green tea, induced sustained satiety, and prevented increases in hunger, which could be success criteria for weight loss. Although appetite contributed to reduced energy intake, a significant reduction of energy intake following CH-19 sweet pepper and capsaicin + green tea consumption was only observed during positive energy balance.

Overall the strongest treatment showed most significant effects on appetite and energy intake, suggesting that synergism of bioactive ingredients is of importance. Previously it has been shown that a combination of bioactive ingredients has a stronger energy intake reducing effect than treatment with single ingredients. Toubro et al.[26] found that body weight loss was greater with caffeine and ephedrine whereas Dulloo et al.[7] showed that stimulating effects of green tea on energy expenditure and substrate oxidation due to caffeine and tea catechins were greater than explained by the active compounds given individually. Recent studies have focused on the effects of combining bioactive ingredients and have found energy intake or appetite reducing effects in both short[27,28] and in long term studies.[29–31] These results support our findings that capsaicin + green tea can induce considerable changes in energy intake. Since CH-19 sweet pepper was an efficient suppressor of energy intake it would be of interest to investigate if a combination of CH-19 sweet pepper and green tea leads to a similar synergistic effect on energy intake. Capsaicin only increases liking of the food when used at lower concentrations[4], and one can only comply with a relatively small dosage of capsaicine over the longer term.[32,33] Therefore we suggest that a lower dosage of capsaicin should be combined with other bioactive ingredients (e.g. CH-19 sweet pepper) in order to reach optimal effects. Green tea is generally liked more in Asian countries than in the western world. Commercially, several approaches have been made to improve liking, for instance adding tastes and flavours such as citrus fruits or pineapple and hibiscus, which are generally well accepted. In scientific practice, subjects use sweeteners and lemon juice to adjust the bitterness of green tea in order to ingest the required amount of catechins.

We conclude that thermogenic food ingredients have energy intake reducing effects when used in combinations, and in positive energy balance. Energy balance did not affect possible treatment induced energy intake, but did affect appetite, thereby supporting negative energy balance. These results suggest that bioactive ingredients (capsaicin, green tea, CH-19) may be helpful in reducing energy intake to prevent body weight gain and may support body weight loss by relatively sustaining satiety and suppressing hunger.

Conflict of interest

None of the authors had a personal or financial conflict of interest. The work was supported by the Directorate for Food, Fisheries and Agri Business, which had no other involvement in the work.

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the data, analyzed and interpreted the data with help from TM. HCR wrote initial draft, AS, PM and MSWP revised the manuscript critically. HCR and MSWP finalized the manuscript and all authors read and approved the final manuscript.

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