Acute effects of mustard, horseradish, black pepper and ginger on energy expenditure, appetite, *ad libitum* energy intake and energy balance in human subjects

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Abstract

Chilli peppers have been shown to enhance diet-induced thermogenesis (DIT) and reduce energy intake (EI) in some studies, but there are few data on other pungent spices. The primary aim of the present study was to test the acute effects of black pepper (pepper), ginger, horseradish and mustard in a meal on 4 h postprandial DIT. The secondary aim was to examine the effects on subjective appetite measures, *ad libitum* EI and energy balance. In a five-way placebo-controlled, single-blind, cross-over trial, twenty-two young (age 24.9 (SD 4.6) years), normal-weight (BMI 21.8 (SD 2.1) kg/m2) males were randomly assigned to receive a brunch meal with either pepper (1.3 g), ginger (20 g), horseradish (8.3 g), mustard (21 g) or no spices (placebo). The amounts of spices were chosen from pre-testing to make the meal spicy but palatable. No significant treatment effects were observed on DIT, but mustard produced DIT, which tended to be larger than that of placebo (14%, 59 (SE 3) kJ/h, respectively, \( P=0.08 \)). No other spice induced thermogenic effects approaching statistical significance. Subjective measures of appetite \( (P=0.85) \), *ad libitum* EI \( (P=0.63) \) and energy balance \( (P=0.67) \) also did not differ between the treatments. Finally, horseradish decreased heart rate \( (P=0.048) \) and increased diastolic blood pressure \( (P=0.049) \) compared with placebo. In conclusion, no reliable treatment effects on appetite, EI or energy balance were observed, although mustard tended to be thermogenic at this dose. Further studies should explore the possible strength and mechanisms of the potential thermogenic effect of mustard actives, and potential enhancement by, for example, combinations with other food components.

Key words: Diet-induced thermogenesis: Bioactive components: Randomised studies: Placebo-controlled studies

The combination of the worldwide obesity epidemic(1) and the fact that long-term weight maintenance following a previous weight loss is often unsuccessful(2) poses a major threat to global health. Thus, approaches for preventing a positive energy balance and thereby weight gain are warranted. Bioactive components from specific pungent spices and teas have in some studies been capable of helping to offset a positive energy balance by increasing thermogenesis(3–5) and decreasing energy intake (EI)(7).

One of the best studied of the pungent spices is chilli peppers(3,4,8–10). Studies have shown that the pungent component, capsaicin, in chilli peppers can increase thermogenesis in both animals(11,12) and human subjects(3,4), although the evidence is not consistent(4,13,14). According to the evidence from rat studies, it seems that this capsaicin-induced increase in thermogenesis is due to the stimulation of catecholamine secretion from the adrenal medulla primarily through the sympathetic activation of the central nervous system(15,10). This effect seems to be mediated through \( \beta \)-adrenergic stimulation, since the effect on thermogenesis disappears after administration with \( \beta \)-blocking agents such as propranolol in both animals(17) and human subjects(4). The transient receptor potential...
vanilloid 1 (TRPV1), which is a nociceptor, has a high affinity for capsaicin\(^{10}\), and thus plays a central role in eliciting the effects of capsaicin on the sympathetic nervous system (SNS). In addition, it has been suggested that capsaicin may affect appetite and EI\(^{20}\).

Despite the evidence of the possible effects of chilli on energy metabolism, the effects of other pungent spices are not well studied. However, infusion of piperine, the pungent component in black pepper, increased catecholamine secretion in anaesthetised rats and thereby stimulated thermogenesis through the SNS\(^{15}\). Likewise, gingerols and shogaols, the major bioactive components in ginger (Zingiber officinale), have been shown to activate the TRPV1 receptor by increasing adrenaline secretion in rats\(^{19}\). However, in human subjects no increase in metabolic rate was seen when ginger was added to a meal compared with when the meal was served alone\(^{20}\).

Mustard (containing the bioactive component allyl isothiocyanate (AITC)) has also been reported to be capable of increasing the metabolic rate in human subjects\(^{21}\), but in that study, the subjects were given mustard in combination with chilli pepper, which makes it impossible to isolate the effect of mustard alone.

Apart from the rather sparse evidence \textit{in vitro} for the effects of these other spices on energy metabolism, the plausibility of the concept is supported \textit{in vitro} data. For example, AITC, gingerols, shogaols and piperine have been shown to bind to the TRPV1 receptors, like capsaicin, which suggests that these components may potentially affect energy expenditure (EE), appetite and EI in a similar way as capsaicin\(^{19,22,23}\).

Combined, we hypothesised that the spicy meals would increase BP and HR. Other blood parameters were included only as explorative endpoints with no associated hypotheses.

In addition, the subjects were asked to refrain from strenuous physical activity for 48 h before each test day. All the subjects signed a written informed consent before participating in the study, which was in accordance with the Declaration of Helsinki and approved by the Municipal Ethical Committee of Copenhagen and Frederiksberg (KF 01-188/00).

The study was registered at ClinicalTrials.gov (ClinicalTrials.gov identifies: NCT 00611156).

**Experimental design**

The study was a five-way crossover, randomised, single-blind (researcher staff were blinded), placebo-controlled design. Subjects were randomised using blockwise Latin square randomisation (for blocks of five subjects).

The specific spices (ginger, horseradish, mustard, black pepper and placebo) were administered as fresh spices added to a test brunch meal. Each test day was separated by a > 3-week washout period to allow subjects to regenerate the blood drawn during the previous test day.

**Respiratory measurements**

The subjects’ RMR and respiratory quotient (RQ) were measured by indirect calorimetry using a ventilated hood system (Oxycon Champion; Meijnhardt BV). RMR, RQ and substrate oxidation were calculated using the formulas by Elia & Livesey\(^{24}\). The precision of the ventilated hood system was validated on a weekly basis by an alcohol burning test; CV was 1.5%.

On each test day, subjects arrived fasting at the Department of Human Nutrition in Frederiksberg, Copenhagen at 07.30 hours. After voiding (emptying of the bladder), the subjects were weighed to the nearest 0.05 kg on a decimal scale (Lindeltronic 8000) and had their body composition (fat-free mass and fat mass) determined by bioelectrical impedance (Animeter; http://doi.org/10.1017/S0007114512001201 Published online by Cambridge University Press)

### Table 1. Subject characteristics at baseline

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>24.9</td>
<td>4.6</td>
<td>19–37</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>73.4</td>
<td>10.3</td>
<td>60.2–97.9</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>183.5</td>
<td>7.8</td>
<td>166–198</td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
<td>21.8</td>
<td>2.1</td>
<td>18.0–25.0</td>
</tr>
<tr>
<td>FM (kg)(^*)</td>
<td>11.0</td>
<td>5.0</td>
<td>2.5–22.1</td>
</tr>
<tr>
<td>FFM (kg)(^*)</td>
<td>62.4</td>
<td>6.2</td>
<td>54.2–75.8</td>
</tr>
</tbody>
</table>

FM, fat mass; FFM, fat-free mass.
\(^*\) Calculated from bioelectrical impedance.
Unitech). At 08.00 hours, a venflon catheter was inserted into the right arm of the subjects and 2 ml were drawn for the measurement of Hb concentration. A three-way stopcock was attached to the venflon catheter to allow repeated blood sampling throughout the test day. Then, the subjects rested in a supine position for 30 min, where respiratory measurements (2 × 25 min) were conducted between 08.30 and 09.30 hours after baseline. The test brunch meal was served at 09.30 hours and followed by 4 h (10.00–14.00 hours) of postprandial respiratory measurements (8 × 25 min).

HR and systolic and diastolic BP were measured every half hour between 09.00 and 14.00 hours using a digital blood pressure monitor (Model UA-787; A&D Medical). Blood samples were also drawn every half hour between 09.30 and 14.00 hours (except at 13.30 hours) for analyses of NEFA, TAG, total cholesterol, HDL, glucose and insulin. LDL levels were estimated using the formula by Friedewald et al. (25). At 14.00 hours, the venflon catheter was removed and the final collection of urine was made. An ad libitum lunch was served at 14.15 hours and after finishing the lunch, the subjects were allowed to leave the department.

**Meals**

All meals were prepared by a specifically educated kitchen staff using standardised recipes.

The standardisation meal consisted of pasta with meat sauce, a multifruit juice and crackers, and was to be eaten before 20.00 hours the evening before the test day. This meal contained 4.5 MJ and had a macronutrient composition of 60% of energy (E%) carbohydrate, 22 E% fat and 18 E% protein.

The test brunch meal was served at 09.30 hours and consisted of bread, ham, butter, raspberry jam, stewed apples, scrambled eggs, shredded beetroot, 250 ml multifruit juice and 200 ml water. In addition to the above-mentioned foods, the test meal contained either (1) 20 g fine-chopped ginger (imported from Thailand by A&C Catering) in the stewed apples, (2) 8.3 g shredded horseradish (from Denmark, A&C Catering) in the shredded beetroot, (3) 21 g Dijon mustard (Maille® Dijon Originale) (corresponding to 14 g DM) in the shredded beetroot, (4) 1.3 g black pepper (imported from Vietnam by KRYTA A/S, INCO) divided between the shredded beetroot and the scrambled eggs or (5) no added spices (placebo). The amounts of spices were chosen from pre-testing to make the meal spicy but palatable. The five different versions of the test meal were aimed at being isoenergetic, but varied slightly due to minor differences in preparation (Table 2). This meal was to be eaten within 20 min.

The ad libitum lunch consisted of pizza with tomato sauce, ham and cheese, and was served with 500 ml water. The amount of water consumed by the subject at the first visit (maximum 500 ml) was reproduced at the subsequent test days. The lunch had an energy content of 1062 kJ/100 g and a macronutrient composition of 56 E% carbohydrate, 27 E% fat and 17 E% protein. The subjects were instructed to eat until comfortably satiated. The ad libitum test meal has previously been shown to be a reproducible method to measure spontaneous EI (26).

**Questionnaires**

A 100 mm visual analogue scale was used to determine changes in subjective appetite sensations during the test day, and completed every half hour between 09.00 and 14.30 hours. Specific scales were as follows: satiety; hunger; fullness; prospective food consumption; thirst; well-being; desire to eat something fatty, sweet, salty and savoury. The use, reproducibility and validity of the VAS have been described in a previous report from this laboratory (27).

The VAS used for subjective evaluation of the visual appeal, smell, taste, aftertaste and overall palatability of the test meals were filled out after the consumption of the test meals. For visual appeal, smell, taste and overall palatability, a low score corresponds to the rating ‘good’, whereas a high score equals the rating ‘bad’. With regard to aftertaste, a low score is associated with ‘much’ aftertaste, whereas a high score is associated with ‘none’.

**Urine collection**

The subjects collected their urine between 08.00 and 14.00 hours in pre-weighed airtight containers. The volume and density of the collected urine was determined and three samples were drawn and stored at −20°C until further analysis. These samples were later analysed for levels of N, adrenaline and noradrenaline.

**Data**

DIT (kJ/h) was calculated as the incremental area under the curve for resting EE after the test meal with RMR used as the baseline measure.

Since the design of the study did not allow for calculation of a normal 24 h-based energy balance, we calculated an estimate of the energy balance using the following equation:

\[
\text{Energy balance} = EI_{\text{test meal}} + EI_{\text{ad libitum meal}} - EE_{4 \text{ h period.}}
\]

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ginger</th>
<th>Horseradish</th>
<th>Mustard</th>
<th>Placebo</th>
<th>Black pepper</th>
</tr>
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<tbody>
<tr>
<td>Energy content (kJ)</td>
<td>2907</td>
<td>2883</td>
<td>2954</td>
<td>2846</td>
<td>2867</td>
</tr>
<tr>
<td>Carbohydrate (E%)</td>
<td>60</td>
<td>59.7</td>
<td>59.6</td>
<td>59.6</td>
<td>59.6</td>
</tr>
<tr>
<td>Fat (E%)</td>
<td>26.1</td>
<td>26.2</td>
<td>26.4</td>
<td>26.5</td>
<td>26.5</td>
</tr>
<tr>
<td>Protein (E%)</td>
<td>13.9</td>
<td>14.1</td>
<td>14</td>
<td>13.9</td>
<td>13.9</td>
</tr>
</tbody>
</table>

E%, percentage of energy.
Statistical analyses

Calculations of sample size were based on data from previous studies on other bioactive ingredients conducted at this laboratory, which are designed to identify a change of 2% in 24 h thermogenesis with a power of 0.8.

Data were analysed by mixed-model ANCOVA. The parameters DIT, RQ, fat and carbohydrate oxidation, ad libitum energy intake, HR, and systolic and diastolic BP were evaluated separately in univariate analyses. Treatment, previous treatment, hood, period (visit number) and interaction between treatment and period were included in the analyses as categorical explanatory variables. Age, body weight, fat-free mass and fat mass were also included in the analyses as covariates and, finally, subject-specific random effects were included to account for inter-subject variability and to adjust for any non-specific differences not captured by the explanatory variables included in the analyses. When the main effect of treatment was significant, post hoc comparisons were made using t tests with the Tukey–Kramer adjustment of P values.

Furthermore, repeated-measures ANCOVA were performed to examine differences in time within periods. In these models, subjects were nested within periods.

The catecholamine data were analysed by ANCOVA with 6 h adrenaline and noradrenaline levels as independent variables. Treatment, previous treatment, period and interaction between treatment and period were included as categorical explanatory variables, whereas age and body weight were included as covariates. Subject-specific random effects were also included.

VAS scores for appetite-related measures were analysed as repeated measures using a mixed-model ANCOVA. Whenever the main effect of treatment was significant, post hoc comparisons were based on t tests with the Tukey–Kramer adjustment of P values. Again, treatment, previous treatment, period and interaction between treatment and period were included as categorical explanatory variables, and age and body weight as covariates, and subjects as a dependent random variable. Subject-specific random effects were also included.

For all statistical models, residuals were examined for normality by histograms and Shapiro–Wilks’s tests, and variance homogeneity was assessed by means of residual plots. All results are presented as means with their standard errors or standard deviations. The significance level was set at $P<0.05$. Statistical analyses were performed using SAS 9.1 (SAS Institute).

Results

Of the twenty-five subjects, two dropped out of the study during their first and second visit, respectively, due to back problems. The subjects reported that their back problems were present before entering the study and thus not caused by the study procedures. A third subject dropped out after the first visit because he disliked some of the food items of the test meal. Thus, twenty-two subjects completed the study and their physical characteristics are shown in Table 1.

Evaluation of the test brunch meal

We observed no difference between the test brunch meals with regard to visual appeal (range 34 (SE 4) to 46 (SE 7) mm, $P=0.22$) and smell (range 35 (SE 3-5) to 46 (SE 4) mm, $P=0.19$), but a tendency towards a treatment effect on the overall palatability of the test meal ($P=0.08$), with the placebo meal being more palatable than the horseradish meal according to post hoc analyses (37.5 (SE 4.5) v. 47.3 (SE 6.1) mm, respectively, $P=0.04$). However, there was a significant treatment effect on the taste of the test meals ($P<0.0003$) with post hoc analyses showing the ginger and horseradish meals to be rated less liked than placebo (48.7 (SE 5.6) v. 28.5 (SE 3.7) mm, $P=0.02$ and 58.4 (SE 5.8) v. 28.5 (SE 3.7) mm, $P<0.0001$, respectively), and tendencies for the mustard and black pepper meals to be better tasting than the horseradish meal (41.4 (SE 5.1) v. 58.4 (SE 5.8) mm, $P=0.07$ and 40.5 (SE 4.9) v. 58.4 (SE 5.8) mm, $P=0.050$, respectively). Finally, there was a significant treatment effect on the aftertaste following the test meal ($P<0.0001$). Post hoc analyses showed that all spiced meals were rated as having more aftertaste than the placebo test meal (range: spicy meals 49.3 (SE 5) to 49.5 (SE 6) mm v. placebo 84.0 (SE 3) mm, $P<0.001$), and that the aftertaste was larger following horseradish compared with both the mustard (19.3 (SE 5) v. 49.5 (SE 6) mm, $P=0.002$) and black pepper (49.3 (SE 5) v. 45.0 (SE 6) mm, $P=0.01$) meals.

Diet-induced thermogenesis

The main statistical analysis showed a treatment effect on DIT ($P=0.004$). Post hoc analyses showed that mustard (59 (SE 3) kJ/h) increased DIT compared with ginger (46 (SE 2) kJ/h, $P=0.003$), horseradish (48 (SE 2) kJ/h, $P=0.004$) and black pepper (49 (SE 3) kJ/h, $P=0.02$), and also tended to increase DIT compared with placebo (52 (SE 2) kJ/h, $P=0.08$) (Fig. 1).

Respiratory quotient and substrate oxidation

There were no significant effects of the treatments on RQ ($P=0.75$), fat or carbohydrate oxidation ($P=0.17$ and $P=0.31$, respectively).

![Fig. 1. Diet-induced thermogenesis (DIT; kJ/h; calculated as the incremental area under the curve) in twenty-two healthy, normal-weight young males after treatment with ginger, horseradish, mustard, placebo and black pepper. Values are means, with their standard errors represented by vertical bars. The repeated-measures statistical analyses (Tukey–Kramer) showed significant differences between mustard and the three other active treatments ($P<0.023$) and a similar tendency of mustard towards placebo ($P=0.083$).]
Catecholamines

We observed no significant effects of the treatments on levels of adrenaline (P = 0.50) or noradrenaline (P = 0.71). For the analysis on the adrenaline data, fat-free mass (P = 0.04), BMI (P = 0.03) and visit (P = 0.049) were significant covariates.

Haemodynamic factors

There was a significant treatment effect on diastolic BP (P = 0.001; Fig. 2). Post hoc analyses revealed that horseradish increased diastolic BP compared with placebo (0·4 mmHg (baseline adjusted), P = 0.049), black pepper (1·9 mmHg (baseline adjusted), P < 0.001) and ginger (1·4 mmHg (baseline adjusted), P = 0.050). No other differences between the treatments were observed. Time (P < 0.0001), baseline levels (P < 0.0001), visit (P < 0.0001) and previous treatment (P = 0.005) were significant covariates. No effects of the treatments were seen on systolic BP (P = 0.15).

Finally, we observed a significant treatment effect on HR (P = 0.007), with post hoc analyses showing a decreased HR following horseradish compared with both mustard and placebo (baseline-adjusted values: 0·4 and 0·8 beats/min, respectively, P = 0.048) (Fig. 3). As expected, the baseline levels of HR (P < 0.0001) and time (P < 0.0001) were significant covariates. Surprisingly, BMI (P = 0.002), visit (P = 0.004) and previous treatment (P = 0.005) were also significant covariates.

Ad libitum energy intake

There were no treatment effects on ad libitum EI (P = 0.62). Ad libitum EI was insignificantly decreased by 26% (−152 kJ v. placebo) following the mustard treatment (5557 (SE 335) kJ) compared with placebo (5709 (SE 281) kJ). Smaller non-significant differences from placebo intake were seen for the remaining treatments: ginger (5672 (SE 378) kJ), horseradish (5616 (SE 320) kJ) and black pepper (5835 (SE 375) kJ).

Appetite measures

There were no treatment effects on the VAS scores for satiety (P = 0.86), hunger (P = 0.90), fullness (P = 0.97) and prospective food intake (P = 0.90). Likewise, no effects of the treatments were observed on measures of well-being (P = 0.42), thirst (P = 0.24), and desires for something sweet (P = 0.69), salty (P = 0.85), fatty (P = 0.68) or savoury (P = 0.54).

Energy balance

Post hoc analyses showed no differences between the treatments in energy balance (P = 0.67).

Blood parameters

Of the analysed blood parameters, significant treatment effects were only observed for HDL levels (P = 0.0002). Post hoc analyses showed that black pepper significantly decreased HDL levels compared with both placebo (P = 0.03) and horseradish (P < 0.0001). Additionally, black pepper also tended to decrease HDL levels compared with mustard (P = 0.059) and ginger (P = 0.07).

Discussion

Overall, none of these spices significantly affected measures of EE, substrate utilisation or appetite relative to the control meal. Only the addition of mustard to a test meal tended to increase DIT compared with placebo. The absolute increase in DIT for mustard v. placebo (approximately 7 kJ/h over 4 h) was very
small, but could make a contribution towards that which could be meaningful on a population basis, though much more so if the effect could be further enhanced in a single meal, or extrapolated to 90–100 kJ/d from three meals.

Minor differences in the energy contents of the test meals (Table 2) may have had small effects on the results, although they are unlikely to explain the entire variation in their thermogenic effects. Based on the thermic effect of macronutrients (28), differences in the DIT of the test meals would be no more than about 7–13 kJ. Furthermore, for the placebo and mustard meals specifically, the energy content of the latter was greater by a factor of 1.14 (295±2846 kJ), whereas DIT was increased by a factor of 1.14 (59/52 kJ/h). Lastly, spices may affect thermogenesis through relatively rapid mechanisms (2–4 h) (3,4,21), whereas the macronutrients have been shown to affect DIT up to 8 h postprandially (28–30). This suggests that any thermic effect of the spices would most probably have been captured by our measuring period, whereas the entire macronutrient-induced DIT may not have been.

The present study indicates little thermogenic effects of the test spices at these levels. However, this is the first report of a potential effect of mustard per se on DIT in human subjects, though the results are only indicative and need to be confirmed. Henry & Emery (21) previously described a significant effect of a chilli-mustard sauce on RMR. They reported an increase in RMR of 153 (SE 8) % for the spiced v. non-spiced meal, and the metabolic rate for both meals reached a maximum at about 75–90 min postprandially (28). Unfortunately, their study design does not allow separation of the effects of mustard and chilli, nor quantification of the actual effect, since RMR was reported as a percentage of fasting RMR (21). It would have been of value to be able to separate these effects, since Simons et al. (31) have shown cross-desensitisation between mustard oil and capsaicin, suggesting potential inter-inhibition between these components.

To our knowledge, only one other human study has investigated the effects of mustard (or AITC) alone on thermogenesis, but this study showed no effect (20). A few studies have shown that AITC can activate different thermosensitive transient receptor potential channels, especially TRPA1 and TRPV1 (25,52,53). This could potentially support an SNS-activated effect of mustard (or any other spice) cause changes in catecholamine levels. Nonetheless, horseradish increased diastolic BP, but at the same time decreased HR, which seems to be inconsistent. To our knowledge, no other human studies have examined the effects of horseradish (or the other examined spices) on these endpoints, but previous studies have shown that an effect of capsaicin on thermogenesis mediated via the SNS can produce a concomitant increase in BP and HR (56,57). However, a recent study in genetically hypertensive rats showed that chronic activation of TRPV1 receptors (by capsaicin) through a cascade of events resulted in lowered BP (58). Thus, our understanding of these potential effects and mechanisms is still limited.

Alternatively, the effect size may simply have been too small, or the effect of mustard may not be the result of a SNS-related mechanism, a view supported by a study in rats showing no effects of AITC on catecholamine secretion (15). Use of a pharmacological SNS-blocking agent (e.g. the β-adrenergic antagonist propranolol) could help clarify this (13).

The lack of differences between the treatments with regard to RQ, fat and carbohydrate oxidation is consistent with the small effects on DIT. However, a recent study showed that intragastric administration of AITC increased carbohydrate oxidation in mice through TRPV1 receptors (39). Nevertheless, the evidence in this area is still very sparse.

We found no effect of the spices on subjective appetite measures or ad libitum EI. However, the ad libitum EI was non-significantly lower (150 kJ, approximately 3 %) following the mustard meal v. the placebo meal. Whether this difference...
is reliable should be examined in future studies. The present study was not designed with ad libitum EI as the main outcome, and thus the time period between the test meal and the ad libitum lunch has most probably been too long (4-5 h). Therefore, we would recommend a shorter interval between such meals in future studies if the aim is to pick up potential effects on ad libitum EI. One way of doing this would be to serve the test meal as a preload shortly before the ad libitum meal. The effects of the tested spices on appetite and ad libitum EI have been examined by two other studies. Reinbach et al. (40) showed that ginger decreased the ad libitum EI, whereas no effects were seen for mustard, chili, horseradish or wasabi, respectively. Only wasabi increased prospective food consumption (40). Finally, a study by Wu et al. (41) showed no effect of ginger on fullness or desire to eat.

Despite the effort put into making the meals equally and highly palatable, the horseradish meal was still rated as being less tasty and palatable than the placebo meal. Likewise, the ginger meal was also rated as less tasty compared with placebo. However, since we observed no treatment differences in subsequent appetite ratings or ad libitum EI, the impact of these differences seems to have been negligible.

Interestingly, due to large variation, the numerical reduction in an ad libitum EI of approximately 150 kJ on mustard vs. placebo was clearly non-significant, whereas the tendency towards a difference in a DIT of approximately 30 kJ during the 4 h was not. Looking at these together in a post hoc analysis of energy balance showed no significant differences between the treatments. Again, this result could potentially have turned out differently if the study had been designed to be more sensitive towards picking up changes in EI. Future studies may benefit from focusing primarily on energy balance (thus EE + EI effects together) and therefore also basing the power calculations on this in order to increase the likelihood of picking up potentially relevant differences around this size (180 kJ) as statistically significant.

The fact that black pepper had HDL-lowering effects could be a side effect of this spice. In one study in rats that examined the effects of long-term (10 weeks) administration of piperine on plasma lipid levels, increased HDL levels and decreased levels of other plasma lipids were found when administered together with a high-fat diet (42). Thus, the effects of piperine on plasma lipid levels may depend on the combination and amounts of macronutrients that are served concomitantly and therefore also needs further investigation.

Conclusion

At palatable levels in food, none of the spices tested here had statistically significant effects on any of the primary or secondary outcome measures relating to energy metabolism, appetite or food intake. Mustard tended to be thermogenic at this dose without adverse effects; however, the effect size was small, and more studies with slightly modified designs are needed to establish the robustness of the possible effects of mustard on DIT (and EI), and whether these could be enhanced at higher doses or novel combinations with other active agents. The present study will be greatly facilitated by improved knowledge of the mechanisms involved and standardisation of the putative bioactive component(s). Likewise, the long-term effects of small but sustained increases in EE due to mustard or other agents merit further study.

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