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Chemesthesis and Health

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Spices and herbs – non-leafy and leafy parts of plants with selected sensory properties, respectively – have a long history of use for the prevention and treatment of a wide variety of health conditions. Their use predates recorded history and they are the mainstay of Ayurvedic and Chinese medicine. These spices and herbs are often used in preparations that include much of the original plant, and in combinations with other plant types, as the balance between elements in the preparations are believed to hold diagnostic and therapeutic value. This practice of combining multiple plant types confounds efforts by Western methodologies to ascribe efficacy to a specific chemical or spice that can be isolated and encapsulated into a dietary supplement or pharmaceutical remedy. Consequently, application of historical knowledge and beliefs about plant-based health remedies has been limited in Western nations. However, with increased awareness of, and interest in, alternative health management techniques has come a growing openness to their potential efficacy for numerous conditions. In the present review, we limit consideration to effects of single pungent spices (i.e., black pepper, chili peppers, cinnamon, ginger, mustard, and saffron) on dimensions of energy balance (i.e., appetite, food intake, energy expenditure, and body weight).

The use of pungent spices is growing exponentially in the United States. Compared to the 1950s when households cooked with 10 or fewer spices, the contemporary American spice rack contains a minimum of 40 different seasonings (Reinagel 2012). Parallel to this expansion of the American spice palette, 2013 marked the first year that the majority (52%) of consumers reported finding hot and spicy flavors appealing. Fruity flavors paired with pungent spices – chipotle lime, mango habañero, and orange chile – are among the flavor combinations topping consumer preferences (Technomic, Inc., 2013 cited in Sloan 2014). While the preferred level of spice varies dramatically worldwide – with high consumers in Mexico ingesting the equivalent of 9 to 25 jalapeño peppers per day (Lopez-Carrillo et al. 2003) and high consumers in the United States eating less than half a pepper daily (Ludy, Mattes 2011) – demand is undoubtedly increasing. On a global scale, it is estimated that one in four individuals consume hot red peppers on a daily basis (Szallasi, Blumberg 1999). The health implications of spices in the food supply are multifold in that consumers, across ethnic groups (Glanz, Basil 1998), rank flavor (90%) as the most influential factor in food choice (Tepper, Trail 1998, Dressler, Smith 2013, International Food Information Council Foundation 2014). In addition, the phytochemicals these spices contribute purportedly moderate risk for a wide range of health conditions (e.g., heart disease, diabetes, cancer, and obesity).

Cultural Patterns of Intake

Cultural and environmental conditions play key roles in individual motivation to consume pungent spices. Use – characterized by the proportion of recipes calling for spices and number of spices per recipe – is positively associated with average annual regional temperature (Billing, Sherman 1998). Tropical countries such as India, Indonesia, Malaysia, and Thailand (average temperature = 27°C) enjoy the greatest intake of pungent spices (e.g., black pepper, garlic, ginger, and onion). Scandinavian countries, such as Finland and Norway (average temperature = 3°C), have the lowest consumption of pungent spices. Similarly, within countries, such as China and the United States, where there is a wide variance in latitude, use of pungent spices increases when approaching the equator (Sherman, Billing 1999). There are multiple potential health-related explanations for this variance, with the most plausible hypotheses relating to body temperature regulation and microbial protection.

From the perspective of body temperature regulation, individuals residing in warmer climates believe that the distinctive "gustatory sweating" – facial flushing extending to the chest and shoulders, and perspiration on the chin, ears, face, forehead, lips, neck, nose, and scalp – evoked by pungent spices produces a cooling effect (Nabhan 2004). This theory is highly prevalent in the historical literature, with demonstrations of marked gustatory sweating when chili peppers were chewed and chili paste was painted on various regions of the oral cavity (Lee 1954, Haxton 1948). For example, pungent foods – among them a native ginger soup – are consumed continuously for 30 days by indigenous postpartum women in Indonesia and Malaysia for the purpose of cooling the body and "sweating away impurities" (Henry, Piggott 1987). Alternatively, residents of cooler climates perceive that pungent spices promote a warming sensation. Among villagers of the Mexican highlands, 69% agree that spicy food "makes me feel warm inside" and 15% believe that "it cools me off" (Rozin, Schiller 1980). This aligns with recent American survey data collected at a Northern latitude with a cooler, non-tropical climate where 57% of university students agreed that spicy food provided an internal warming sensation while only 4% indicated that it evoked cooling (Ludy 2013).

Although seemingly contradictory, both warming and cooling effects have been demonstrated in the experimental literature with hot red peppers, mustard, and ginger. Core (tympanic) temperature increased in a Japanese study where healthy young adults (n=5M, 7F) ingested whole hot red peppers containing 0.1 mg/kg capsaicin (the compound responsible for their pungency) (Hachiya et al. 2007). Similarly, core (rectal) temperature increased in an Australian study where male endurance athletes (n=6) consumed a traditional meal with a spicy sauce containing 3 g each of Tabasco sauce and hot English mustard (Edwards et al. 1992). In an American study with healthy young adults (n=14M, 11F), 1 g cayenne red pepper (2 mg capsaicin) mixed into a meal increased core (ingested sensor) temperature, while promoting evaporative cooling by reducing skin (neck) temperature (Ludy, Mattes 2011). Animal data support this dual role of capsaicin in body temperature perception. When a single dose of capsaicin (5 mg/kg) was injected into Wistar rats, it independently facilitated heat production (i.e., oxygen consumption) via the brainstem and induced heat loss (i.e., decreased tail temperature suggesting vasodilation) via the forebrain (Osaka et al. 2000). Another study showed no variation in body temperature when male Wistar rats were chronically fed a 2% ginger-containing chow – the highest dose that rats will reliably eat. In contrast, rapid, dose-dependent decreases in body temperature and metabolic rate were demonstrated following single intraperitoneal injections of ginger (2.5 or 25 mg/kg) (Ueki et al. 2008).

From a microbial perspective, use of pungent spices may serve as a cultural response to protect populations from foodborne microorganisms. Analyses of “traditional” recipes across every continent and most major linguistic groups – those that predate widespread access to refrigeration – show great variability in the individual types of spices used. However, a few overall trends can be detected. First, annual regional temperature and spice use in general are positively correlated. For example, Indian cuisine incorporates 25 different spices with an average recipe calling for 9.3 spices, while Norwegian cuisine includes 10 different spices with an average of only 1.6 spices per recipe. This is noteworthy because annual temperature is a relative indicator of food spoilage and there is no correlation between the number of spices grown in a country and its temperature (Sherman, Billing 1999). Second, meat-based recipes contain more spices than plant-based recipes regardless of geographical region (3.9 vs. 2.4, respectively) (Sherman, Hash 2001). This is notable given that unrefrigerated meats spoil more quickly and are more likely to result in foodborne illness outbreaks than plant-based foods (Sockett 1995). Third, there is a positive relationship between use of highly antimicrobial spices and average temperature – within and between countries. A review compiling the data from laboratory testing of 30 common spices (e.g., black pepper and ginger) – both powdered or as purified active ingredients – demonstrated that all inhibited (i.e., killed or slowed the growth of) at least 25% of foodborne bacterial species – such as *Clostridium botulinum, Listeria monocytogenes, Escherichia coli, Salmonella pullorum,* and *Staphylococcus aureus* – that are common in foodborne illness outbreaks and widely distributed globally. Fifteen highly antimicrobial spices – including chili peppers, cinnamon, and mustard – killed at least 75% of foodborne bacteria (Billing, Sherman 1998). This suggests that adding pungent spices to the food prepared in hot climates, where foodborne illness is more likely to occur, has greater potential to provide antibacterial protection. Finally, the concentrations of spices used in traditional cooking – generally 0.25 to 3 g/kg – are sufficient to yield bacterial inhibition (Sherman, Hash 2001). This is important, because it implies that health benefits can be achieved by eating well-accepted spicy foods that are part of traditional cuisines – not swallowing encapsulated powders or employing pharmacologic intervention, likely increasing consumer acceptance and sustainability of effects.

Appetite

It is intuitive that appetitive sensations are important drivers of ingestive behavior and, as a consequence, health. This has spawned interest in the possible role of pungent spices on appetite and intake. There are numerous reviews summarizing this perspective (Ludy, Moore & Mattes 2012, Whiting, Derbyshire & Tiwari 2012, Mattes 2012). Of course, spices are often added to foods to enhance their appeal and, presumably, stimulate intake. Such use has not attracted the same level of scientific scrutiny. Both roles are reviewed here following a brief consideration of the indices of appetite.

Briefly, appetite is commonly divided into more focused sensations in the literature. “Hunger” refers to the sensations that prompt the initiation of an eating or drinking event. It is often regarded as a reflection of energy-based need. “Desire to eat” sensations may also lead to meal initiation, but are related more strongly to cognitive and sensory cues. So, it is possible to not be hungry and have a strong desire to eat, as may occur when presented with palatable desserts after a large meal. These two sensations largely determine eating frequency. “Prospective consumption,” or a rating of how much an individual could consume at a point in time, is a purported predictor of portion size. The term “fullness” is primarily used to describe the sensations that terminate an eating event. Thus, it determines portion size. It is not simply the opposite of hunger, as different mechanisms underlie the two sensations. For example, hunger has been linked to the concentrations of ghrelin, whereas fullness is more tied to cholecystokinin (CCK), glucagon-like peptide-1 (GLP-1), and peptide YY (PYY), among many other gut peptides (Hameed, Dhillo & Bloom 2009). Total energy intake is a function of eating frequency and portion size, so the balance between hunger, desire to eat, and fullness is critical. The literature also contains references to satiation and satiety. The former refers to the sensations that determine portion size and when the meal is terminated, while the latter is an index of the inter-meal interval or eating frequency. However, in some instances, the amount consumed in a challenge meal provided at a set time following some dietary intervention is used as a metric for satiety.

Suppression of Appetitive Sensations

Hot Red Pepper. There is substantial literature on the appetitive effects of capsaicin, a lipophilic alkaloid responsible for the irritancy of hot red peppers, though much of this work fails to acknowledge the importance of customary exposure. As described above, high concentrations of hot red peppers are common in some cuisines and not in others. Because familiarity is an important determinant of acceptability, discrepant responses may be obtained across cultures. In an early Japanese trial, healthy females (n=13 habitual spicy food consumers) ingested high-fat and high-carbohydrate breakfast meals with and without 10 g dried red pepper (providing 30 mg capsaicin). Following the high-fat meal, ratings of hunger, desire to eat, and prospective consumption all rose in the 3 hours before an *ad libitum* lunch when no red pepper was consumed, but were suppressed when red pepper was included (Yoshioka et al. 1999). Fullness was not altered by red pepper ingestion, nor was any rating after the high-carbohydrate meals. Thus, capsaicin ingestion dampened a number of the appetitive responses that would presumably promote energy intake after the high-fat meal. This occurred at a higher level of spiciness than customary meals, but without reports that the red pepper dose rendered the food as unpleasant. In contrast to the favorable hedonic ratings provided by Japanese and Korean participants to the high capsaicin doses consumed in early studies (Yoshioka et al. 1998, Lim et al. 1997), the same doses were deemed highly unacceptable by less familiar Western populations in the United States and the Netherlands (Ludy, Moore & Mattes 2012, Reinbach, Martinussen & Møller 2010) and likely led to lower appetitive ratings and intake based on the discomfort they produced.

To determine whether more moderate concentrations in foods judged as palatable would also suppress appetitive sensations has been addressed in several acute and longer-term trials. In one acute

Danish study, participants (n=17M, 23F who liked hot spices) received lower capsaicin doses (0.375 mg, divided equally between dried chili powder and freshly ground chili) mixed into a starter meal and followed by an *ad libitum* buffet (Reinbach, Martinussen & Møller 2010). The mean palatability rating of the food with chili pepper was about 6 on a 9-point scale (9=like very much). While there was a small increase in the desire to eat items with selected qualities (e.g., sweetness), overall effects on appetite were weak. Similar findings were obtained with other spicy foods including horseradish, ginger, mustard, and wasabi. Another acute study conducted in the United States evaluated the effects of capsaicin provided through doses indicated by individual participants as palatable (mean dose ~1 g dried cayenne red pepper, providing 2 mg capsaicin and 53,800 Scoville Heat Units (SHU) per gram) in a serving of tomato soup (Ludy, Mattes 2011). No effect of the red pepper was measured for hunger, fullness, prospective consumption, or desire to eat any food.

It has been proposed that the addition of capsaicin to the diet of energy-restricted individuals would augment satiety sensations and aid dietary adherence (Smeets, Janssens & Westerterp-Plantenga 2013, Janssens, Hursel & Westerterp-Plantenga 2014). In a 36-hour Dutch study where individuals were administered a diet providing either 100% or 75% of estimated energy needs, participants (n=8M, 7F) were administered 1.03 g red pepper (2.5 mg capsaicin and 39,050 SHU) prior to eating a meal (Janssens, Hursel & Westerterp-Plantenga 2014). Palatability ratings were comparable across conditions. Under energy balance, the addition of red pepper led to heightened area under the curve (AUC) fullness ratings, but no difference in hunger or desire to eat. When energy intake was restricted, there was no difference in any appetitive index between periods with and without added capsaicin. In another similar 36-hour Dutch trial (n=12M, 12F) with a 20% energy restriction and including manipulation of protein concentrations, 24-hour AUC values (36-hour values were not reported) were higher when capsaicin was consumed relative to control conditions under energy balance or 20% energy restriction (Smeets, Janssens & Westerterp-Plantenga 2013). However, the addition of capsaicin did not offset the reduction of fullness due to energy restriction and the addition of protein led to a greater appetitive effect than the capsaicin. Hunger and desire to eat ratings were not reported. In a longer-term trial where Dutch participants were administered 135 mg/d encapsulated capsaicin (45 mg before each of 3 meals daily for 3 months; n=12M, 30F) or placebo (n=11M, 38F), no significant effects were noted for hunger or satiety (Lejeune et al., 2003).

The effects of capsaicin on appetite are heavily dependent on the perceived irritation it provides. In Dutch work (n=12M, 12F) where the addition of capsaicin to a meal resulted in augmented fullness, this was not observed when an equivalent dose was ingested in capsule form (Westerterp-Plantenga, Smeets & Lejeune 2005). In addition, American participants (n=4M, 8F) who do not customarily consume spicy foods reportedly reduce their desire to eat foods with selected properties (e.g., fatty, salty) relative to the same foods consumed without red pepper (Ludy, Mattes 2011). However, these differences are not observed in spicy food consumers (n=10M, 3F).

Because of the confounding effects of dose, palatability, customary exposure level, and current state of energy balance, it is not possible to determine the magnitude of an independent appetite-suppressing effect of capsaicin. In one Dutch trial (n=12M, 12F; Smeets, Janssens & Westerterp-Plantenga 2013), capsaicin exerted a weaker effect than manipulation of protein, but the latter's effects are complex (Masic, Yeomans 2014) hampering a direct comparison. Based on current evidence, it can only be concluded that larger effects are apparent with higher doses, especially if they are perceived as irritating and exposure occurs when individuals are in a state of relative energy balance as opposed to energy deficit. It is not possible to discern differential effects on the various dimensions of appetitive sensations. Nevertheless, several mechanisms have been proposed for an appetite suppressive effect of capsaicin. One holds that it prompts the release of gut peptides associated with satiety, such as GLP-1 (Reinbach et al. 2009). Evidence that an ingested dose in which the pungency is not sensed is ineffective suggests that appetitive regulation is dependent on neural activation in the oral cavity (i.e., a cephalic phase response) rather than post-ingestive signaling or metabolism. Other work documents that oral exposure activates the sympathetic nervous system leading to the hypothesis that augmented fullness could be attributable to elevated catecholamine concentrations (Yoshioka et al. 1999). Again, the oral irritation is likely responsible and this is modulated by customary levels of capsaicin use and learned flavor preferences. Aversive sensations are more effective at promoting fullness than palatable sensations.

Cinnamon. Among individuals with type 2 diabetes, cinnamon reportedly moderates serum glucose, triglyceride, low-density lipoprotein cholesterol, and total cholesterol concentrations when ingested at doses of 3 (Solomon, Blannin 2009), 5 (Solomon, Blannin 2007), and 6 g/d (Khan et al. 2003). Less consistent findings have been reported with 1.5 (Khan, Khan & Shah 2010, Vanschoonbeek et al. 2006) and 3 g/d (Mang et al. 2006), or an extract providing the equivalent of 20 g/d (Ziegenfuss et al. 2006). Based on the hypothesis that changes of blood glucose and/or insulin drive hunger (Flint et al. 2007), cinnamon has been hypothesized to reduce hunger. However, in a Swedish crossover study where healthy participants without diabetes (n=8M, 6F) consumed rice pudding with or without 6 g cinnamon, there was no difference in reported hunger/satiety rated on a category scale ranging from extreme hunger (-10) to extreme satiety (+10) (Hlebowicz et al. 2007).

Ginger. Various gastrointestinal tract disorders – including diarrhea, dyspepsia, flatulence, nausea, and vomiting – call for ginger as a traditional remedy. This is attributed in part to ginger's enhancement of gastric emptying (Wu et al. 2008, Hu et al. 2011). More rapid emptying would move the ingesta into the small intestine more quickly. This would thereby stimulate the release of satiety peptides such as CCK, GLP-1, and PYY, which would theoretically increase fullness ratings. However, the appetitive response to this property is unclear. Ginger could also reduce fullness ratings by diminishing signaling from gastric stretch receptors. In a small American study, where overweight males (n=10) ingested 2 g ginger in hot water, participants reported significantly lower hunger and prospective consumption, as well as a trend for higher fullness relative to a placebo treatment (Mansour et al. 2012). In contrast, studies in male Wistar rats indicate that ginger increases energy intake (Ueki et al. 2008, Wadikar, Premavalli 2011). Studies on the relationship between ginger (1.2 g loads administered in capsules), gastric emptying, and appetite document the effect of the spice on gastric emptying, but fail to support an effect on appetitive sensations (Wu et al. 2008, Hu et al. 2011) – even among those with symptoms of dyspepsia (Hu et al. 2011). Possibly, the lower concentration and mode of ginger administration (as capsules that bypass oral sensory stimulation), as well as the small experimental energy loads provided, result in the failure of these latter trials to identify treatment effects on appetite.

Saffron. Anxiolytic properties have led to the hypothesis that saffron may ameliorate a stress-related desire to eat and snack (Gout, Bourges & Paineau-Dubreuil 2010). This was tested in a French trial where overweight female participants were administered capsules with 176.5 mg of a saffron extract named "Satiereal" (n=31) or a matched placebo (n=29). A small, but statistically significant larger proportion of treated participants indicated the extract reduced their hunger and need to snack. No effect on satiation, or the desire to eat sweet or fatty snacks, was observed. Whether the posited mode of action was responsible for the outcome will require additional testing.

The limited evidence available on the effects of pungent spices other than capsaicin on appetitive sensations precludes conclusions about their efficacy. At present, there is only suggestive evidence of modest activity for cinnamon, ginger, and saffron. However, this should not be interpreted as grounds to dismiss their potential influence as spice use may be more sustainable than many other proposed dietary modifications aimed at modifying appetite. Small, but sustained effects may ultimately exert a stronger impact than a large, but transient effect.

Enhancement of Appetitive Sensations

Rather than attributing an orexigenic property to any particular spice, work in this area has focused on how enhancing the flavor of foods can promote appetitive sensations and energy intake. A number of researchers posited that flavor fortification or enhancement could boost appetite and intake for populations suffering from chemosensory deficits, such as the elderly. These studies have yielded mixed effects (Schiffman, Warwick 1988, Schiffman 1993, de Graaf, Polet & van Staveren 1994, Griep, Mets & Massart 2000, Koskinen, Kälviäinen & Tuorila 2003, Essed et al. 2007, Mathey et al. 2001, Best, Appleton 2011). This is likely attributable to the fact that deficits of chemosensory function in older adults are often due primarily to the effects of chronic diseases and medication use, leading to idiosyncratic changes and, presumably, remedial approaches. Thus, there is no clear single regimen to enhance the sensory experience appropriately. Other work has attempted to use spices to enhance the appeal of less palatable foods (Savage et al. 2013, Henry et al. 2003). This work has focused on intake rather than appetite as an outcome.

Decreased Energy Intake

Although it is often assumed that appetitive sensations are closely correlated with energy intake, this is not necessarily the case. Energy intake is modulated by numerous non-appetitive factors such as social custom, food availability, cost, and health beliefs (International Food Information Council Foundation 2014). Understanding the effects of pungent spices on appetite is independently important, as appetite does affect quality of life. However, if energy intake is the outcome of primary interest, this is the behavior that should be measured.

Hot Red Pepper. Early Japanese work with capsaicin indicated its inclusion in a breakfast meal (10 g red pepper, 30 mg capsaicin) did not alter energy intake at the subsequent meal (n=13F), though the macronutrient distribution of the lunch meal was altered (Yoshioka et al. 1999). In contrast, a Canadian study (n=10M) serving an appetizer (6 g red pepper, 18 mg capsaicin) just prior to lunch did result in lower energy intake at an *ad libitum* lunch meal and snack (-189 kcal; Yoshioka et al. 1999). A later study by the same group added red pepper to a soup and noted only a trend for reduced energy intake for Japanese males (n=16) at the highest dose (2.8 mg capsaicin and 55,000 SHU) (Yoshioka et al.

2004). With exposures at a dose of 0.9 g red pepper (3.8 mg capsaicin and 80,000 SHU) over 2 days, a significant reduction in daily energy intake (about -125 kcal) was observed when the spice was added to tomato juice or ingested in capsules swallowed with tomato juice. However, the effect was greater with oral exposure (Westerterp-Plantenga, Smeets & Lejeune 2005). Another trial involving Danish adults (n=17M, 23F) using a lower, palatable dose of capsaicin reported no effect of capsaicin intake on energy or gram weight of food intake (Reinbach, Martinussen & Møller 2010). Reflecting the importance of customary exposure effects on participant responses, another study conducted in the United States (n=10M, 3F regular spicy food users; n=4M, 8F non-users) observed a reduction of energy intake (-66 kcal) at a challenge meal presented 4.5 hours after a meal containing capsaicin, but only among those with low customary exposure (Ludy, Mattes 2011). Other Dutch work (n=8M, 7F) noting only a trend for lower intake associated with capsaicin exposure revealed it was present only under conditions of energy balance (-143 kcal) and not during energy deficit (Janssens, Hursel & Westerterp-Plantenga 2014). Thus, there is limited evidence that oral exposure to capsaicin reduces energy intake under conditions that maintain food palatability.

Increased Energy Intake

As noted above, there are limited data indicating pungent spices can be used to increase energy intake by enhancing the appeal of foods. In one American trial (n=16M, 18F), herb-flavored dip was used to promote intake of vegetables among preschoolers. The addition of various spices led to fewer rejections and greater gram intake of vegetables (Savage et al. 2013). One Chinese pilot study in hospitalized elderly individuals (n=7M, 14F) observed higher energy intake with flavors and spices including ginger, garlic, sesame oil, oyster sauce, spiced soy sauce, and soybean paste compared to unflavored foods (Henry et al. 2003). However, energy intake was still well below energy needs. Other work has revealed that the use of spices may lead to variable effects on food palatability, while energy intake remains unchanged (Reinbach, Martinussen & Møller 2010, Markey et al. 2011, Gregersen et al. 2013).

Spices have also been used to compensate for reduced food appeal when selected ingredients linked to health are purposefully modified. In one American trial (n=47M, 101F), spices were added to enhance the appeal of reduced-fat foods in adults (Peters et al. 2014). The foods with added spice were rated as more palatable and comparable to the full-fat versions. It is assumed this would lead to greater energy intake, but this was not measured. A similar approach has been attempted in a British study (n=69M, 79F) with reduced sodium foods (Ghawi, Rowland & Methven 2014). Here again, over time, the spices successfully maintained the appeal of a low sodium soup, though acute energy intake was not altered. In female swine tested while transitioning between diets – a time when energy intake often drops – the addition of “hot-flavored spices” led to marked individual differences in acceptance/preference with no overall change in energy intake (Clouard, Val-Laillet 2014). Whether this strategy will work in the long-term with animals who like particular spices will require further study.

Another approach to spice use in maintaining the palatability of foods modified for some therapeutic use is to add selected spices that are commonly associated with the other flavor-active component to compensate for the latter’s elimination. For example, vanilla is often associated with sweetness, so will the addition of vanilla permit a reduction of sugar without loss of appeal? Preliminary evidence suggests there may be some efficacy to this approach (Blank & Mattes 1990), but further testing over nutritionally-relevant timeframes is required to ascertain its value.

An additional variation in the use of spices to enhance intake entails adding them to foods to increase sensory variety and, as a result, dietary acceptability. Monotony can lead to reduced intake (Zandstra, de Graaf & Van Trijp 2000), so where it is deemed desirable to promote intake of a single food or limited set of foods, it may be possible to add spices to combat monotony effects. For example, there is a considerable literature suggesting nuts provide an array of health benefits, but to realize them, this limited class of foods must be eaten regularly (Jones et al. 2014b). While a plausible hypothesis, in a 12-week trial comparing peanut intake between groups provided a single flavor (honey roasted, salted, spicy, or unsalted) or combination of three flavors, no effect of the flavor compounds on energy intake was observed (Jones et al. 2014a). Whether this was due to a property of peanuts that renders them resistant to monotony effects, the trial duration was too short to measure differential responses, or the diversity of specific flavor compounds were not optimal, could not be determined and warrants further investigation.

Cinnamon. Energy intake has been monitored in a limited number of studies exploring effects of cinnamon exposure. In one American trial, participants were provided Cinnulin PF® (a water-soluble cinnamon extract) at a dose of 500 mg (equivalent to 10 g whole cinnamon powder and containing at least 1% of the putative active polyphenol polymer; n=8M, 4F) or placebo capsules (n=3M, 7F) twice per day. There was a trend for the Cinnulin-treated group to increase daily energy intake over 12 weeks compared to placebo treatment (+241 vs. -93 kcal/d, respectively) (Ziegenfuss et al. 2006).

Taken together the data provide very limited support for a positive influence of pungent spices on energy intake. Ultimately, it is more likely efficacy will depend on their contribution to palatability rather than a metabolic effect. The most promising use may be their addition to foods with lower acceptability due to purposeful manipulation (e.g., salt, sugar, or fat reduction) for some intended purpose. There are currently no data implicating spice use with positive energy balance.

Thermogenesis

Consumption of pungent spices is often linked to enhanced thermogenesis (i.e., augmented energy expenditure and/or substrate oxidation). While hot red pepper (capsaicin) is the best studied of the pungent spices, limited data exists on the thermogenic effects of black pepper (piperine); ginger (gingerols, shogaols, and zingerone); and mustard (allyl isothiocyanate). Allyl isothiocyanate is an organosulfur compound, while capsaicin, piperine, and gingerols all have similar chemical structures with an aromatic ring and an alkyl side-chain with carbonyl function (Astrup et al. 2010) (Figure 1). Likeness in chemical structure may contribute to similarities in thermogenic effects, as the intensity of pungency is affected by alterations in the alkyl side-chain (e.g., chain length, degree of unsaturation, alkyl end grouping) or amide group position near the polar aromatic end (DeMan 2013). The leading explanation for the thermogenic effects of these spices is stimulation of the sympathetic nervous system by the binding of pungent compounds to thermosensitive ion receptors, namely TRPV1 (transient receptor potential cation channel, subfamily V, member 1) and TRPA1 (transient receptor potential cation channel, subfamily A, member 1; Eldershaw et al. 1994, Okumura et al. 2010). Through this mechanism, the pungent principles of the spices stimulate the secretion of catecholamines from the adrenal medulla (Kawada et al. 1988, Yoshioka et al. 1995). Previous investigations indicate that oral sensory exposure, compared to gastrointestinal exposure via encapsulated powders, augments thermogenesis (Westerterp-Plantenga, Smeets & Lejeune 2005, Ludy, Mattes 2011). Some investigations suggest that thermogenic effects are greatest with palatable flavors (LeBlanc, Brondel 1985), while others suggest that unpleasant flavors produce the greatest effects (Ludy, Mattes 2011).

Hot Red Peppers (Capsaicin)

Capsaicin is the best studied of the pungent compounds and exerts thermogenic effects by activating TRPV1 receptors, commonly termed “capsaicin receptors” (Caterina et al. 1997). Numerous human studies have demonstrated that capsaicin increases energy expenditure (Yoshioka et al. 1995, Yoshioka et al. 1998, Matsumoto et al. 2000, Lejeune, Kovacs & Westerterp-Plantenga 2003, Ludy, Mattes 2011, Chaiyata, Puttadechakum & Komindr 2003) and substrate oxidation (Yoshioka et al. 1995, Yoshioka et al. 1998, Lim et al. 1997, Matsumoto et al. 2000, Lejeune, Kovacs & Westerterp-Plantenga 2003, Ludy, Mattes 2011, Shin, Moritani 2007). For example, in an American study where participants (n=14M, 11F) were fed 1 g cayenne red pepper (2 mg capsaicin) mixed into a tomato soup lunch, 4.5 hour postprandial energy expenditure increased by 10 kcal and fat oxidation was augmented (Ludy, Mattes 2011). Similarly, in Dutch participants (n=23M, 68F) resting energy expenditure was increased 119 kcal/d and fat oxidation was enhanced during a 3-month weight maintenance period following a 5-10% weight loss with daily ingestion of 135 mg capsaicin in encapsulated supplements (Lejeune, Kovacs & Westerterp-Plantenga 2003). Additionally, in a Thai investigation where healthy participants (n=12F) consumed a glucose drink mixed with 5 g fresh chili pepper (3.5 mg capsaicin), postprandial energy expenditure was increased 12.1% at 5 minutes, 4.7% at 15 minutes, and 5.2% at 30 minutes after capsaicin ingestion (Chaiyata, Puttadechakum & Komindr 2003).

However, there have been conflicting reports. For example, most studies indicate an augmentation of fat oxidation (Yoshioka et al. 1998, Lejeune, Kovacs & Westerterp-Plantenga 2003, Shin, Moritani 2007, Ludy, Moore & Mattes 2012, Ludy, Mattes 2011), while fewer studies suggest increases in carbohydrate oxidation (Yoshioka et al. 1995, Lim et al. 1997, Matsumoto et al. 2000). Other studies find no thermogenic effects (Ahuja et al. 2007, Smeets, Westerterp-Plantenga 2009), or reductions in postprandial energy expenditure (Ahuja et al. 2006). A few plausible explanations for these mixed results may be considered.

One explanation is that body composition moderates thermogenic effects. All studies demonstrating increased thermogenesis following capsaicin consumption were conducted in lean individuals (Yoshioka et al. 1995, Yoshioka et al. 1998, Matsumoto et al. 2000, Lejeune, Kovacs & Westerterp-Plantenga 2003, Ludy, Mattes 2011), or did not report body composition (Chaiyata, Puttadechakum & Komindr 2003). In contrast, an Australian randomized crossover trial where participants (n=14M, 22F) were instructed to consume a 30 g chili blend (55% cayenne red pepper) daily for 4 weeks, demonstrated no effect on 2-hour postprandial diet-induced thermogenesis or substrate oxidation for the entire sample. However, energy expenditure was reduced among overweight and obese individuals (Ahuja et al. 2006, Ahuja et al. 2007). Likewise, when Japanese women with no long-term history of spicy food use consumed 3 mg capsaicin in a yellow curry sauce at breakfast, energy expenditure increased in lean (n=8F), but not overweight or obese (n=8F) participants (Matsumoto et al. 2000). Similar thermogenic effects have been noted with caffeinated coffee. Whereas caffeine stimulates thermogenesis in both lean and obese individuals, the magnitude is greater for lean individuals with larger increases in energy expenditure (Bracco et al. 1995) and enhanced fat oxidation (Acheson et al. 1980).

Alternatively, the dose may mediate the thermogenic response. A meta-analysis showed that higher doses (135-150 mg capsaicin, equivalent to 45-50 g cayenne red pepper or 13-15 jalapeño peppers per day) provide the greatest thermogenic effects (Ludy, Moore & Mattes 2012). In line with this finding, a Dutch randomized crossover trial where participants (n=11M, 19F) were served a low-dose (1 g) cayenne red pepper lunch containing pasta, sausage, and tomato sauce showed no effect on 3.5-hour postprandial energy expenditure compared to a pepper-free lunch (Smeets, Westerterp-Plantenga 2009). A caveat is that large doses require compliance. This may have contributed to the lack of significant thermogenic differences in "naïve or infrequent consumers" who were supposed to consume 16.5 g cayenne red pepper (33 mg capsaicin) per day (Ahuja et al. 2006, Ahuja et al. 2007). Similar compliance issues have been noted with the bitter flavors of catechins and caffeine in tea (Hursel, Viechtbauer & Westerterp-Plantenga 2009).

Black Pepper (Piperine)

Piperine, an alkaloid, is the primary chemical compound responsible for the pungency of black pepper. It has the dual role of activating two thermosensitive receptors, TRPV1 (McNamara, Randall & Gunthorpe 2005) and TRPA1 (Okumura et al. 2010). Piperine stimulates TRPV1 more strongly than TRPA1, but not as strongly as capsaicin or allyl isothiocyanate (present in mustard) (Okumura et al. 2010). However, piperine is better absorbed than capsaicin (97% vs. 80%, respectively) (Ganesh Bhat, Chandrasekhara 1986, Iwai, Yazawa & Watanabe 2003). It is the most commonly consumed spice worldwide and is increasingly being consumed to stimulate metabolism (Szallasi 2005); however, the reports of its effects on thermogenesis are sparse and contradictory. When piperine was infused into the hindlimb of male Wistar rats, it stimulated oxygen uptake in a dose-dependent manner (Eldershaw et al. 1994). In another study of male Wistar rats, administration of piperine led to increased catecholamine secretion, particularly epinephrine, which is suggestive of thermogenic enhancement by the sympathetic nervous system (Kawada et al. 1988). In contrast, a study of male Swiss albino mice demonstrated reduced thyroid hormone concentrations – both triiodothyronine (T3) and thyroxin (T4) – after 15 days of daily oral piperine administration, which suggests decreased thermogenesis (Panda, Kar 2003).

To date, only two human studies have investigated the effects of piperine on energy expenditure and thermogenesis. The first was a Danish randomized crossover trial where participants (n=22 healthy young males who liked spicy food) ingested a brunch meal with 1.3 g black pepper divided between shredded beetroot and scrambled eggs. Four-hour postprandial diet-induced thermogenesis and substrate oxidation did not vary for the piperine meal compared to a no-pepper control (Gregersen et al. 2013). The second was an American randomized crossover trial where participants (n=17 overweight post-menopausal females) were fed 1.5 g black pepper (68.6 mg piperine) divided equally between three meals while undergoing whole room indirect calorimetry for 24 hours. Similar to the other human investigation, piperine did not alter energy expenditure or substrate oxidation compared to a no-pepper control (O'Connor et al. 2013).

Ginger (Gingerols, Shogaols, and Zingerone)

The main chemical compounds responsible for the irritancy of ginger are the gingerols, contained in fresh ginger, and the shogaols and zingerone, which are both dehydration and degradation products of the gingerols (Dedov et al. 2002). Collectively, these compounds activate TRPV1 receptors and increase the secretion of epinephrine, suggesting a role for sympathetic nervous system involvement in ginger's thermogenic effects (Liu, Simon 1996, Dedov et al. 2002, Iwasaki et al. 2006, Kawada et al. 1988). When extracts of fresh and dried ginger were infused into the hindlimb of male Wistar rats, oxygen consumption was stimulated. Gingerol displayed the greatest thermogenic effects, while shogaols demonstrated a more modest augmentation of energy expenditure. Notably, high concentrations of ginger extracts inhibited oxygen consumption (Eldershaw et al. 1992).

There are three human investigations related to the thermogenic effects of ginger. In a British investigation, participants (n=3M, 5F) were served a breakfast prepared with 30 g fresh, grated ginger. This had no effect on two-hour postprandial diet-induced thermogenesis, compared to a ginger-free breakfast (Henry, Piggott 1987). In a Danish randomized crossover trial, participants (n=22 healthy young males who liked spicy food) ingested a brunch meal with 20 g finely chopped ginger mixed into stewed apples. Similarly, four-hour postprandial diet-induced thermogenesis and substrate oxidation did not vary for the ginger meal compared to a no-ginger control (Gregersen et al. 2013). In contrast, an American investigation provided participants (n=10 overweight men) a hot ginger beverage containing 2 g dried ginger powder along with breakfast. The ginger beverage yielded a 43 kcal/d increase in post-prandial thermogenesis relative to hot water (Mansour et al. 2012). The varied findings may be explained by the form of ginger administration. Dried ginger, not fresh, contains shogaols, which increase ginger's pungency (Suekawa et al. 1984).

Mustard (Allyl Isothiocyanate)

Allyl isothiocyanate, an organosulfur compound, is responsible for the pungency of mustard. Like the pungent compounds in black pepper and ginger, allyl isothiocyanate binds to both TRPV1 (Ohta, Imagawa & Ito 2007, Everaerts et al. 2011) and TRPA1 receptors (Jordt et al. 2004, Iwasaki et al. 2008). In a study of female Sprague-Dawley rats, intramuscular injection of isothiocyanate augmented brown adipose tissue activity (Yoshida et al. 1988). However, a separate study failed to demonstrate catecholamine stimulation when allyl isothiocyanate was infused into the femoral vein of male Wistar rats (Kawada et al. 1988).

Reports of the thermogenic effects of mustard are sparse. Two human investigations were identified. In a Danish randomized crossover trial, participants (n=22 healthy young males who liked spicy food) ingested a brunch meal with 21 g Dijon mustard mixed into shredded beetroot. Four-hour postprandial diet-induced thermogenesis tended to increase by 14% following the mustard meal, compared to a no-mustard control (14.1 vs. 12.4 kcal/hr, respectively; p=0.08) (Gregersen et al. 2013). In a British investigation, participants (n=12) were served a breakfast prepared with 3 g mustard sauce and 3 g chili sauce. Three-hour postprandial diet-induced thermogenesis following the spiced breakfast increased 25%, compared to a spice-free breakfast (153 vs. 128% resting metabolic rate, respectively; p<0.01) (Henry, Emery 1986). However, it is not possible to distinguish the effects of capsaicin (chili) and allyl isothiocyanate (mustard). This is particularly limiting since a subsequent investigation demonstrated cross-desensitization between mustard oil and capsaicin (Simons, Carstens & Carstens 2003). Additionally, previous studies suggest that a synergism may exist between bioactive ingredients where combinations produce greater thermogenic effects than single ingredients. For example, a Swiss investigation (n=10 healthy males) showed that the effects of green tea on energy expenditure and fat oxidation were more than could be explained by caffeine or catechins alone (Dulloo et al. 1999).

Collectively, the thermogenic data presented in this section provide modest support for the effects of pungent spices on energy balance. With hot red pepper, the most pronounced enhancements in energy expenditure and fat oxidation occur at higher doses, among lean individuals, and with oral sensory exposure. While human data on the thermogenic effects of other spices are sparse, form (e.g., dried vs. fresh) and combination (i.e., single vs. multiple spices) may play important roles. Through the drying process, spices (e.g., ginger) may acquire greater pungency. Additional effects may occur when combining spices (e.g., red pepper and mustard). The roles of customary exposure and palatability in mediating thermogenic effects require further investigation.

Body Weight

Few published studies have been of sufficient duration to measure changes of body weight related to the use pungent spices. Most have hypothesized anorexigenic and thermogenic effects and/or inhibition of pancreatic enzyme activity, augmented metabolic rate, and prevention of adipocyte differentiation resulting in weight loss (Westerterp-Plantenga et al. 2006, Astrup et al. 2010, Kazemipoor et al. 2012, González-Castejón, Rodriguez-Casado 2011). There are also reports of various pungent spices, especially capsaicin, diminishing (Nopanitaya 1973) or facilitating energy absorption (Platel et al. 2002, Pradeep, Geervani & Eggum 1991). Capsaicin and piperine have been reported to stimulate the activity of enzymes at the intestinal brush border membrane and to increase microvilli length thereby increasing the absorptive surface (Prakash, Srinivasan 2010). This is desirable for nutrient absorption, but increased permeability for ions and macromolecules could also pose a risk for food allergies and intolerance (Jensen-Jarolim et al. 1998).

Despite the various mechanisms described, results of spice use to moderate body weight or fat mass have generally not been supportive. In one 8-week trial with Wistar rats, the addition of clove, ginger, red pepper, or black pepper to Yaji (a Nigerian meat sauce) had no significant effect on body weight (Akpamu et al. 2011). Similarly, clove exerted no effect on body weight in adult albino rats over a 90-day trial (Agbaje, Adeneye & Daramola 2009). In contrast, weight gain has been reported in Wistar rats following the ingestion of black pepper for 35 (Hassan et al. 2010) and 55 days (Mbongue et al. 2005). In one French human trial, administration of Satiereal (a saffron extract described above) via capsules led to a progressive loss of body weight (-1 kg) over an 8-week period compared to a placebo treatment (Gout, Bourges & Paineau-Dubreuil 2010). Whether this would be modified if participants had ingested the spice in a manner that provided oral stimulation has not been examined, nor has the sustainability of the effect. Another American trial provided a mixture of chromium picolinate, inulin, capsicum, L-phenylalanine, and other lipotropic compounds to adults (n=3M, 53F) on an energy-restricted diet and activity regimen (Hoeger et al. 1998). No effect was observed relative to the control group (n=9M, 58F).

The efficacy of capsaicin to aid in maintenance of reduced body weight has also been tested. Following a 4-week very-low-energy diet that did or did not include 135 mg/d capsaicin, Dutch participants (n=23M, 68F) were monitored for three months (Lejeune, Kovacs & Westerterp-Plantenga 2003). While fat oxidation was elevated in the capsaicin-treated group (n=12M, 30F), there was no difference from placebo (n=11M, 38F) in body weight. Thus, despite mechanistic, appetitive, and acute feeding studies results providing evidence of the plausibility of spices to moderate body weight, the very limited evidence from longer-term trials has not yielded the expected results.

Individual Variability

Individual variability in responses to different spices, doses, and modes of delivery likely hampers identification of the potential health effects of spice ingestion. Increasing knowledge of the factors contributing to variability should permit experimental control and better isolation of useful properties. Dose is an obvious critical methodological factor that must be reconciled to compare findings across trials. However, this is not straightforward since the sensory impact of the dose varies according to the food in which it is delivered and the prior experience of the consumer with the spice. Nearly all the work on individual differences has focused on capsaicin. Findings on whether individuals with prior experience with capsaicin rate its burn lower than those without experience are mixed (Stevenson, Prescott 1994, Ludy, Mattes 2012, Byrnes, Hayes 2013). However, users rate spicy food as more pleasant than non-users (Ludy, Mattes 2012). The time required to induce a hedonic shift for the burn or sting of capsaicin or to recover from it has not been determined, but one British trial noted an increase in acceptability over a 5-week period (Stevenson, Yeomans 1995). Individuals who consume foods containing capsaicin report higher liking for spicy foods (e.g., horseradish, mustard, and wasabi) and cuisines (e.g., Chinese, Indian, and Mexican) (Ludy, Mattes 2012). This is specific to spicy foods as users and non-users do not differ in hedonic ratings for non-spicy items such as apples, bread, chicken, lettuce, milk, and rice (Ludy, Mattes 2012). Prior dietary experience with capsaicin may help reconcile discrepant responses between individuals or within individuals over time.

Capsaicin may also modify the experience of other tastes present in a food, especially sourness, bitterness, and umami (Simons, O'Mahony & Carstens 2002). There is a direct dose-response association, but how this may interact with prior experience with capsaicin is not well characterized. Because capsaicin specifically alters the perception of some tastes and odors, it may alter the flavor of foods (i.e., the totality of the sensory experience) and would be expected to modify acceptability ratings. The masking effect does not alter flavor identification and occurs equally in users and non-users (Lawless, Rozin & Shenker 1985), but the hedonic impact is not comparably altered (Stevenson, Yeomans 1993). In one British trial, non-users were indifferent to liked concentrations by users whereas strong doses were comparably disliked (Stevenson, Yeomans 1993).

The timing of stimulus presentation is also critical as a pause of only 2.5-5.0 minutes between stimulations may allow the onset of desensitization and lower burn intensity ratings (Green 1989, Green, Rentmeister-Bryant 1998). Such pauses are likely under customary dining conditions so may lead to underestimations of the contribution of capsaicin to the irritancy and acceptability of foods when it occurs. The reverse effect, sensitization (i.e., growth of sensation with repeated stimulation), does not appear to be functional during food ingestion (Prescott 1999). The composition of the food containing capsaicin also alters the burn it elicits with stronger ratings for lower concentrations in water than lipid vehicles (Lawless, Hartono & Hernandez 2000). Personality traits are also linked to capsaicin intake. There is a positive association between consumption of foods containing capsaicin and sensation seeking and sensitivity to reward (Ludy, Mattes 2012, Byrnes, Hayes 2013) and for women only, extroversion (Ludy, Mattes 2012).

Conclusion

Pungent spices contribute many potential beneficial health properties (Figure 2). Although the energy balance effects of spices are small in magnitude, they should not be discounted. Nutritionally-relevant outcomes are present at modest doses, enhanced with oral exposure, and found in traditional ethnic recipes. At these low doses, and even when several times greater than typical human intake, the potential for adverse effects is low (Srinivasan 2005). Collectively, this indicates that pungent spices are unlikely to incite harm, may aid in food safety, and hold a potentially therapeutic role in weight management.

References

Acheson, K., Zahorska-Markiewicz, B., Pittet, P., Anantharaman, K. & Jequier, E. 1980, "Caffeine and coffee: their influence on metabolic rate and substrate utilization in normal weight and obese individuals", *American Journal of Clinical Nutrition,* vol. 33, no. 5, pp. 989-997.

Agbaje, E., Adeneye, A. & Daramola, A. 2009, "Biochemical and toxicological studies of aqueous extract of Syzigium aromaticum (l.) Merr. & perry (myrtaceae) in rodents", *African Journal of Traditional, Complementary and Alternative Medicines,* vol. 6, no. 3, pp. 241-254.

Ahuja, K.D.K., Robertson, I.K., Geraghty, D.P. & Ball, M.J. 2006, "Effects of chili consumption on postprandial glucose, insulin, and energy metabolism", *American Journal of Clinical Nutrition,* vol. 84, no. 1, pp. 63-69.

Ahuja, K.D.K., Robertson, I.K., Geraghty, D.P. & Ball, M.J. 2007, "The effect of 4-week chilli supplementation on metabolic and arterial function in humans", *European Journal of Clinical Nutrition,* vol. 61, no. 3, pp. 326-333.

Akpamu, U., Nwaopara, A., Izunya, A., Oaikhena, G., Okhiai, O., Idonije, B. & Osifo, U. 2011, "A comparative study on weight changes in rats fed with diet containing *Yaji, Yaji*-additives and *Yaji*-spices", *Biology and Medicine,* vol. 3, no. 5, pp. 6-15.

Astrup, A., Kristensen, M., Gregersen, N.T., Belza, A., Lorenzen, J.K., Due, A. & Larsen, T.M. 2010, "Can bioactive foods affect obesity?", *Annals of the New York Academy of Sciences,* vol. 1190, no. 1, pp. 25-41.

Best, R.L. & Appleton, K.M. 2011, "Comparable increases in energy, protein and fat intakes following the addition of seasonings and sauces to an older person's meal", *Appetite,* vol. 56, no. 1, pp. 179-182.

Billing, J. & Sherman, P.W. 1998, "Antimicrobial functions of spices: why some like it hot", *Quarterly Review of Biology,* , pp. 3-49.

Bracco, D., Ferrarra, J.M., Arnaud, M.J., Jequier, E. & Schutz, Y. 1995, "Effects of caffeine on energy metabolism, heart rate, and methylxanthine metabolism in lean and obese women", *The American Journal of Physiology,* vol. 269, no. 4, pp. E671-E678.

Byrnes, N.K. & Hayes, J.E. 2013, "Personality factors predict spicy food liking and intake", *Food Quality and Preference,* vol. 28, no. 1, pp. 213-221.

Caterina, M.J., Schumacher, M.A., Tominaga, M., Rosen, T.A., Levine, J.D. & Julius, D. 1997, "The capsaicin receptor: a heat-activated ion channel in the pain pathway", *Nature,* vol. 389, no. 6653, pp. 783-784.

Chaiyata, P., Puttadechakum, S. & Komindr, S. 2003, "Effect of chili pepper (Capsicum frutescens) ingestion on plasma glucose response and metabolic rate in Thai women.", *Journal of the Medical Association of Thailand,* vol. 86, no. 9, pp. 854-60.

Clouard, C. & Val-Laillet, D. 2014, "Impact of sensory feed additives on feed intake, feed preferences, and growth of female piglets during the early postweaning period", *Journal of animal science,* vol. 92, no. 5, pp. 2133-2140.

de Graaf, C., Polet, P. & van Staveren, W.A. 1994, "Sensory perception and pleasantness of food flavors in elderly subjects", *Journal of Gerontology,* vol. 49, no. 3, pp. P93-P99.

Dedov, V.N., Tran, V.H., Duke, C.C., Connor, M., Christie, M.J., Mandadi, S. & Roufogalis, B.D. 2002, "Gingerols: a novel class of vanilloid receptor (VR1) agonists", *British Journal of Pharmacology,* vol. 137, no. 6, pp. 793-798.

DeMan, J.M. 2013, *Principles of food chemistry,* Springer, New York.

Dressler, H. & Smith, C. 2013, "Food choice, eating behavior, and food liking differs between lean/normal and overweight/obese, low-income women", *Appetite,* vol. 65, no. 1, pp. 145-152.

Dulloo, A.G., Duret, C., Rohrer, D., Girardier, L., Mensi, N., Fathi, M., Chantre, P. & Vandermander, J. 1999, "Efficacy of a green tea extract rich in catechin polyphenols and caffeine in increasing 24-h energy expenditure and fat oxidation in humans", *The American Journal of Clinical Nutrition,* vol. 70, no. 6, pp. 1040-1045.

Edwards, S.J., Montgomery, I.M., Colquhoun, E.Q., Jordan, J.E. & Clark, M.G. 1992, "Spicy meal disturbs sleep: an effect of thermoregulation?", *International Journal of Psychophysiology,* vol. 13, no. 2, pp. 97-100.

Eldershaw, T.P., Colquhoun, E.Q., Bennett, K.L., Dora, K.A. & Clark, M.G. 1994, "Resiniferatoxin and piperine: capsaicin-like stimulators of oxygen uptake in the perfused rat hindlimb", *Life Sciences,* vol. 55, no. 5, pp. 389-397.

Eldershaw, T.P.D., Colquhoun, E.Q., Dora, K.A., Peng, Z.C. & Clark, M.G. 1992, "Pungent principles of ginger (*Zingiber officinale*) are thermogenic in the perfused rat hindlimb", *International Journal of Obesity,* vol. 16, no. 10, pp. 755-763.

Essed, N.H., van Staveren, W.A., Kok, F.J. & de Graaf, C. 2007, "No effect of 16 weeks flavor enhancement on dietary intake and nutritional status of nursing home elderly", *Appetite,* vol. 48, no. 1, pp. 29-36.

Everaerts, W., Gees, M., Alpizar, Y.A., Farre, R., Leten, C., Apetrei, A., Dewachter, I., Van Leuven, F., Vennekens, R. & De Ridder, D. 2011, "The capsaicin receptor TRPV1 is a crucial mediator of the noxious effects of mustard oil", *Current Biology,* vol. 21, no. 4, pp. 316-321.

Flint, A., Gregersen, N.T., Gluud, L.L., Møller, B.K., Raben, A., Tetens, I., Verdich, C. & Astrup, A. 2007, "Associations between postprandial insulin and blood glucose responses, appetite sensations and energy intake in normal weight and overweight individuals: a meta-analysis of test meal studies", *British Journal of Nutrition,* vol. 98, no. 1, pp. 17-25.

Ganesh Bhat, B. & Chandrasekhara, N. 1986, "Studies on the metabolism of piperine: absorption, tissue distribution and excretion of urinary conjugates in rats", *Toxicology,* vol. 40, no. 1, pp. 83-92.

Ghawi, S.K., Rowland, I. & Methven, L. 2014, "Enhancing consumer liking of low salt tomato soup over repeated exposure by herb and spice seasonings", *Appetite,* vol. 81, no. 1, pp. 20-29.

Glanz, K. & Basil, M. 1998, "Why Americans eat what they do: Taste, nutrition, cost, convenience, and weight control concerns", *Journal of the American Dietetic Association,* vol. 98, no. 10, pp. 1118-1126.

González-Castejón, M. & Rodriguez-Casado, A. 2011, "Dietary phytochemicals and their potential effects on obesity: a review", *Pharmacological Research,* vol. 64, no. 5, pp. 438-455.

Gout, B., Bourges, C. & Paineau-Dubreuil, S. 2010, "Satiereal, a Crocus sativus L extract, reduces snacking and increases satiety in a randomized placebo-controlled study of mildly overweight, health women", *Nutrition Research,* vol. 30, no. 5, pp. 305-313.

Green, B.G. & Rentmeister-Bryant, H. 1998, "Temporal characteristics of capsaicin desensitization and stimulus-induced recovery in the oral cavity", *Physiology & Behavior,* vol. 65, no. 1, pp. 141-149.

Green, B.G. 1989, "Capsaicin sensitization and desensitization on the tongue produced by brief exposures to a low concentration", *Neuroscience Letters,* vol. 107, no. 1-3, pp. 173-178.

Gregersen, N.T., Belza, A., Jensen, M., Ritz, C., Bitz, C., Hels, O., Frandsen, E., Mela, D. & Astrup, A. 2013, "Acute effects of mustard, horseradish, black pepper and ginger on energy expenditure, appetite, ad libitum energy intake and energy balance in human subjects", *British Journal of Nutrition,* vol. 109, no. 3, pp. 556-563.

Griep, M.I., Mets, T.F. & Massart, D.L. 2000, "Effects of flavour amplification of Quorn® and yoghurt on food preference and consumption in relation to age, BMI and odour perception", *British Journal of Nutrition,* vol. 83, no. 2, pp. 105-113.

Hachiya, S., Kawabata, F., Ohnuki, K., Inoue, N., Yoneda, H., Yazawa, S. & Fushiki, T. 2007, "Effects of CH-19 Sweet, a non-pungent cultivar of red pepper, on sympathetic nervous activity, body temperature, heart rate, and blood pressure in humans.", *Bioscience, Biotechnology, and Biochemistry,* vol. 71, no. 3, pp. 671-676.

Hameed, S., Dhillo, W. & Bloom, S. 2009, "Gut hormones and appetite control", *Oral Diseases,* vol. 15, no. 1, pp. 18-26.

Hassan, D., Ogah, D., Yusuf, N., Musa, M. & Saidu, G. 2010, "The effect of acute and chronic (short and long term) oral administrations of black pepper (Piper guineense) aqueous extract on the body weight and haematological values of albino-Wistar rat", *Journal of Medicinal Plants,* vol. 4, no. 12, pp. 1122-1125.

Haxton, H.A. 1948, "Gustatory sweating", *Brain: A Journal of Neurology,* vol. 71, no. 1, pp. 16-25.

Henry, C.J.K., Woo, J., Lightowler, H.J., Yip, R., Lee, R., Hui, E., Shing, S. & Seyoum, T.A. 2003, "Use of natural food flavours to increase food and nutrient intakes in hospitalized elderly in Hong Kong", *International Journal of Food Sciences and Nutrition,* vol. 54, no. 4, pp. 321-327.

Henry, C.J. & Emery, B. 1986, "Effect of spiced food on metabolic rate", *Human Nutrition - Clinical Nutrition,* vol. 40, no. 2, pp. 165-168.

Henry, C.J. & Piggott, S.M. 1987, "Effect of ginger on metabolic rate", *Human Nutrition - Clinical Nutrition,* vol. 41, no. 1, pp. 89-92.

Hlebowicz, J., Darwiche, G., Bjorgell, O. & Almer, L.O. 2007, "Effect of cinnamon on postprandial blood glucose, gastric emptying, and satiety in healthy subjects", *American Journal of Clinical Nutrition,* vol. 85, no. 6, pp. 1552-1556.

Hoeger, W.W., Harris, C., Long, E.M. & Hopkins, D.R. 1998, "Four-week supplementation with a natural dietary compound produces favorable changes in body composition", *Advances in Therapy,* vol. 15, no. 5, pp. 305-314.

Hu, M.L., Rayner, C.K., Wu, K.L., Chuah, S.K., Tai, W.C., Chou, Y.P., Chiu, Y.C., Chiu, K.W. & Hu, T.H. 2011, "Effect of ginger on gastric motility and symptoms of functional dyspepsia", *World Journal of Gastroenterology,* vol. 17, no. 1, pp. 105-110.

Hursel, R., Viechtbauer, W. & Westerterp-Plantenga, M. 2009, "The effects of green tea on weight loss and weight maintenance: a meta-analysis", *International Journal of Obesity,* vol. 33, no. 9, pp. 956-961.

International Food Information Council Foundation 2014, June 24, 2014-last update*, Food & Health Survey: The Pulse of America's Diet: From Beliefs to Behaviors*. Available: http://www.foodinsight.org/articles/2014-food-and-health-survey [2014, August 7].

Iwai, L., Yazawa, W. & Watanabe, T. 2003, "Roles as metabolic regulators of the non nutrients, capsaicin and capsiate, supplemented to diets", *Proceedings of the Japan Academy,* vol. 79, no. 7, pp. 207-212.

Iwasaki, Y., Morita, A., Iwasawa, T., Kobata, K., Sekiwa, Y., Morimitsu, Y., Kubota, K. & Watanabe, T. 2006, "A nonpungent component of steamed ginger—[10]-shogaol—increases adrenaline secretion via the activation of TRPV1", *Nutritional Neuroscience,* vol. 9, no. 3-4, pp. 169-178.

Iwasaki, Y., Tanabe, M., Kobata, K. & Watanabe, T. 2008, "TRPA1 agonists—allyl isothiocyanate and cinnamaldehyde—induce adrenaline secretion", *Bioscience, Biotechnology, and Biochemistry,* vol. 72, no. 10, pp. 2608-2614.

Janssens, P.L., Hursel, R. & Westerterp-Plantenga, M.S. 2014, "Capsaicin increases sensation of fullness in energy balance, and decreases desire to eat after dinner in negative energy balance", *Appetite,* vol. 77, no. 1, pp. 46-51.

Jensen-Jarolim, E., Gajdzik, L., Haberl, I., Kraft, D., Scheiner, O. & Graf, J. 1998, "Hot spices influence permeability of human intestinal epithelial monolayers", *Journal of Nutrition,* vol. 128, no. 3, pp. 577-581.

Jones, J.B., Provost, M., Keaver, L., Breen, C., Ludy, M. & Mattes, R.D. 2014a, "Effects of daily consumption of one or varied peanut flavors on acceptance and intake", *Appetite,* .

Jones, J.B., Provost, M., Keaver, L., Breen, C., Ludy, M.J. & Mattes, R.D. 2014b, "A randomized trial on the effects of flavorings on the health benefits of daily peanut consumption", *American Journal of Clinical Nutrition,* vol. 99, no. 3, pp. 490-496.

Jordt, S., Bautista, D.M., Chuang, H., McKemy, D.D., Zygmunt, P.M., Högestätt, E.D., Meng, I.D. & Julius, D. 2004, "Mustard oils and cannabinoids excite sensory nerve fibres through the TRP channel ANKTM1", *Nature,* vol. 427, no. 6971, pp. 260-265.

Kawada, T., Sakabe, S., Watanabe, T., Yamamoto, M. & Iwai, K. 1988, "Some pungent principles of spices cause the adrenal medulla to secrete catecholamine in anesthetized rats.", *Proceedings of the Society for Experimental Biology and Medicine,* vol. 188, no. 2, pp. 229-233.

Kazemipoor, M., Radzi, Che Wan Jasimah Wan Mohamed, Cordell, G.A. & Yaze, I. 2012, "Potential of traditional medicinal plants for treating obesity: a review", *International Conference on Nutrition and Food Sciences,* vol. 39, no. 1, pp. 1-6.

Khan, R., Khan, Z. & Shah, S. 2010, "Cinnamon may reduce glucose, lipid and cholesterol level in type 2 diabetic individuals", *Pakistan Journal of Nutrition,* vol. 9, no. 5, pp. 430-433.

Khan, A., Safdar, M., Ali Khan, M.M., Khattak, K.N. & Anderson, R.A. 2003, "Cinnamon improves glucose and lipids of people with type 2 diabetes", *Diabetes Care,* vol. 26, no. 12, pp. 3215-3218.

Koskinen, S., Kälviäinen, N. & Tuorila, H. 2003, "Flavor enhancement as a tool for increasing pleasantness and intake of a snack product among the elderly", *Appetite,* vol. 41, no. 1, pp. 87-96.

Lawless, H., Rozin, P. & Shenker, J. 1985, "Effects of oral capsaicin on gustatory, olfactory and irritant sensations and flavor identification in humans who regularly or rarely consume chili pepper", *Chemical Senses,* vol. 10, no. 4, pp. 579-589.

Lawless, H.T., Hartono, C. & Hernandez, S. 2000, "Thresholds and suprathreshold intensity functions for capsaicin in oil and aqueous based carriers", *Journal of Sensory Studies,* vol. 15, no. 4, pp. 437-477.

LeBlanc, J. & Brondel, L. 1985, "Role of palatability on meal-induced thermogenesis in human subjects", *American Journal of Physiology - Endocrinology and Metabolism,* vol. 248, no. 3, pp. 333-336.

Lee, T.S. 1954, "Physiological gustatory sweating in a warm climate", *Journal of Physiology,* vol. 124, no. 3, pp. 528-542.

Lejeune, M.P.G.M., Kovacs, E.M.R. & Westerterp-Plantenga, M.S. 2003, "Effect of capsaicin on substrate oxidation and weight maintenance after modest body-weight loss in human subjects", *British Journal of Nutrition,* vol. 90, no. 3, pp. 651-659.

Lim, K., Yoshioka, M., Kikuzato, S., Kiyonaga, A., Tanaka, H., Shindo, M. & Suzuki, M. 1997, "Dietary red pepper ingestion increases carbohydrate oxidation at rest and during exercise in runners", *Medicine & Science in Sports & Exercise,* vol. 29, no. 3, pp. 355-361.

Liu, L. & Simon, S.A. 1996, "Similarities and differences in the currents activated by capsaicin, piperine, and zingerone in rat trigeminal ganglion cells", *Journal of Neurophysiology,* vol. 76, no. 3, pp. 1858-1869.

Lopez-Carrillo, L., Lopez-Cervantes, M., Robles-Diaz, G., Ramirez-Espitia, A., Mohar-Betancourt, A., Meneses-Garcia, A., Lopez-Vidal, Y. & Blair, A. 2003, "Capsaicin consumption, Helicobacter pylori positivity and gastric cancer in Mexico", *International Journal of Cancer,* vol. 106, no. 2, pp. 277-282.

Ludy, M.J. 2013, "Some like it hot: characteristics underlying spicy food preference and aversion", *FASEB Journal,* vol. 27, pp. 1035.17.

Ludy, M.J. & Mattes, R.D. 2012, "Comparison of sensory, physiological, personality, and cultural attributes in regular spicy food users and non-users", *Appetite,* vol. 58, no. 1, pp. 19-27.

Ludy, M.J. & Mattes, R.D. 2011, "The effects of hedonically acceptable red pepper doses on thermogenesis and appetite", *Physiology & Behavior,* vol. 102, no. 3, pp. 251-258.

Ludy, M.J., Moore, G.E. & Mattes, R.D. 2012, "The effects of capsaicin and capsiate on energy balance: critical review and meta-analyses of studies in humans", *Chemical Senses,* vol. 37, no. 2, pp. 103-121.

Mang, B., Wolters, M., Schmitt, B., Kelb, K., Lichtinghagen, R., Stichtenoth, D. & Hahn, A. 2006, "Effects of a cinnamon extract on plasma glucose, HbA1c, and serum lipids in diabetes mellitus type 2", *European Journal of Clinical Investigation,* vol. 36, no. 5, pp. 340-344.

Mansour, M.S., Ni, Y., Roberts, A.L., Kelleman, M., RoyChoudhury, A. & St-Onge, M. 2012, "Ginger consumption enhances the thermic effect of food and promotes feelings of satiety without affecting metabolic and hormonal parameters in overweight men: A pilot study", *Metabolism,* vol. 61, no. 10, pp. 1347-1352.

Markey, O., McClean, C.M., Medlow, P., Davison, G.W., Trinick, T.R., Duly, E. & Shafat, A. 2011, "Effect of cinnamon on gastric emptying, arterial stiffness, postprandial lipemia, glycemia, and appetite responses to high-fat breakfast", *Cardiovascular Diabetology,* vol. 10, no. 9, pp. 78.

Masic, U. & Yeomans, M.R. 2014, "Umami flavor enhances appetite but also increases satiety", *American Journal of Clinical Nutrition,* vol. 100, no. 2, pp. 532-538.

Mathey, M.F., Siebelink, E., de Graaf, C. & Van Staveren, W.A. 2001, "Flavor enhancement of food improves dietary intake and nutritional status of elderly nursing home residents", *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences,* vol. 56, no. 4, pp. M200-M205.

Matsumoto, T., Miyawaki, C., Ue, H., Yuasa, T., Miyatsuji, A. & Moritani, T. 2000, "Effects of capsaicin-containing yellow curry sauce on sympathetic nervous system activity and diet-induced thermogenesis in lean and obese young women", *Journal of Nutritional Science and Vitaminology,* vol. 46, no. 6, pp. 309-315.

Mattes, R.D. 2012, "Spices and energy balance", *Physiology & Behavior,* vol. 107, no. 4, pp. 584-590.

Mbongue, F., Kamtchouing, P., Essame, O., Yewah, P., Dimo, T. & Lontsi, D. 2005, "Effect of the aqueous extract of dry fruits of Piper guineense on the reproductive function of adult male rats", *Indian Journal of Pharmacology,* vol. 37, no. 1, pp. 30-32.

McNamara, F.N., Randall, A. & Gunthorpe, M.J. 2005, "Effects of piperine, the pungent component of black pepper, at the human vanilloid receptor (TRPV1)", *British Journal of Pharmacology,* vol. 144, no. 6, pp. 781-790.

Nabhan, G.P. 2004, *Why some like it hot: food, genes, and cultural diversity,* Shearwater Books, Washington DC.

Nopanitaya, W. 1973, "Long term effects of capsaicin on fat absorption and the growth of the rat", *Growth,* vol. 37, no. 3, pp. 269-279.

O'Connor, A., Corbin, K.D., Nieman, D.C. & Swick, A.G. 2013, "A randomized, controlled trial to assess short-term black pepper consumption on 24-hour energy expenditure and substrate utilization", *Functional Foods in Health and Disease,* vol. 3, no. 10, pp. 377-388.

Ohta, T., Imagawa, T. & Ito, S. 2007, "Novel agonistic action of mustard oil on recombinant and endogenous porcine transient receptor potential V1 (pTRPV1) channels", *Biochemical Pharmacology,* vol. 73, no. 10, pp. 1646-1656.

Okumura, Y., Narukawa, M., Iwasaki, Y., Ishikawa, A., Matsuda, H., Yoshikawa, M. & Watanabe, T. 2010, "Activation of TRPV1 and TRPA1 by black pepper components", *Bioscience, Biotechnology, and Biochemistry,* vol. 74, no. 5, pp. 1068-1072.

Osaka, T., Kobayashi, A., Lee, T.H., Namba, Y., Inoue, S. & Kimura, S. 2000, "Lack of integrative control of heat production and heat loss after capsaicin administration", *Pflügers Archiv - European Journal of Physiology,* vol. 440, no. 3, pp. 440-445.

Panda, S. & Kar, A. 2003, "Piperine lowers the serum concentrations of thyroid hormones, glucose, and hepatic 5'D activity in adult male mice", *Hormone and Metabolic Research,* vol. 9, no. 35, pp. 523-526.

Peters, J.C., Polsky, S., Stark, R., Zhaoxing, P. & Hill, J.O. 2014, "The influence of herbs and spices on overall liking of reduced fat food", *Appetite,* vol. 79, no. 1, pp. 183-188.

Platel, K., Rao, A., Saraswathi, G. & Srinivasan, K. 2002, "Digestive stimulant action of three Indian spice mixes in experimental rats", *Food/Nahrung,* vol. 46, no. 6, pp. 394-398.

Pradeep, K.U., Geervani, P. & Eggum, B. 1991, "Influence of spices on utilization of sorghum and chickpea protein", *Plant Foods for Human Nutrition,* vol. 41, no. 3, pp. 269-276.

Prakash, U.N. & Srinivasan, K. 2010, "Beneficial influence of dietary spices on the ultrastructure and fluidity of the intestinal brush border in rats", *British Journal of Nutrition,* vol. 104, no. 1, pp. 31-39.

Prescott, J. 1999, "The generalizability of capsaicin sensitization and desensitization", *Physiology & Behavior,* vol. 66, no. 5, pp. 741-749.

Reinagel, M. 2012, *Today's Contemporary Spice Cabinet*.

Reinbach, H.C., Martinussen, T. & Møller, P. 2010, "Effects of hot spices on energy intake, appetite, and sensory specific desires in humans", *Food Quality and Preference,* vol. 21, no. 6, pp. 655-661.

Reinbach, H.C., Smeets, A., Martinussen, T., Møller, P. & Westerterp-Plantenga, M.S. 2009, "Effects of capsaicin, green tea and CH-19 sweet pepper on appetite and energy intake in humans in negative and positive energy balance", *Clinical Nutrition,* vol. 28, no. 3, pp. 260-265.

Rozin, P. & Schiller, D. 1980, "The nature and acquisition of a preference for chili pepper by humans", *Motivation and Emotion,* vol. 4, no. 1, pp. 77-101.

Savage, J.S., Peterson, J., Marini, M., Bordi Jr, P.L. & Birch, L.L. 2013, "The addition of a plain or herb-flavored reduced-fat dip is associated with improved preschoolers' intake of vegetables", *Journal of the Academy of Nutrition and Dietetics,* vol. 113, no. 8, pp. 1090-1095.

Schiffman, S.S. 1993, "Perception of taste and smell in elderly persons", *Critical Reviews in Food Science & Nutrition,* vol. 33, no. 1, pp. 17-26.

Schiffman, S.S. & Warwick, Z.S. 1988, "Flavor enhancement of foods for the elderly can reverse anorexia", *Neurobiology of Aging,* vol. 9, no. 1, pp. 24-26.

Sherman, P.W. & Billing, J. 1999, "Darwinian Gastronomy: Why We Use Spices Spices taste good because they are good for us", *Bioscience,* vol. 49, no. 6, pp. 453-463.

Sherman, P.W. & Hash, G.A. 2001, "Why vegetable recipes are not very spicy", *Evolution and Human Behavior,* vol. 22, no. 3, pp. 147-163.

Shin, K.O. & Moritani, T. 2007, "Alterations of autonomic nervous activity and energy metabolism by capsaicin ingestion during aerobic exercise in healthy men", *Journal of Nutritional Science and Vitaminology,* vol. 53, no. 2, pp. 124-132.

Simons, C.T., Carstens, M.I. & Carstens, E. 2003, "Oral irritation by mustard oil: self-desensitization and cross-desensitization with capsaicin", *Chemical Senses,* vol. 28, no. 6, pp. 459-465.

Simons, C.T., O'Mahony, M. & Carstens, E. 2002, "Taste suppression following lingual capsaicin pre-treatment in humans", *Chemical Senses,* vol. 27, no. 4, pp. 353-365.

Sloan, A.E. 2014, "What, When and Where America Eats", *Food Technology,* vol. 68, no. 1, pp. 20-31.

Smeets, A.J., Janssens, P.L. & Westerterp-Plantenga, M.S. 2013, "Addition of capsaicin and exchange of carbohydrate with protein counteract energy intake restriction effects on fullness and energy expenditure", *Journal of Nutrition,* vol. 143, no. 4, pp. 442-447.

Smeets, A. & Westerterp-Plantenga, M. 2009, "The acute effects of a lunch containing capsaicin on energy and substrate utilisation, hormones, and satiety", *European Journal of Clinical Nutrition,* vol. 48, no. 4, pp. 229-234.

Sockett, P. 1995, "The epidemiology and costs of diseases of public health significance, in relation to meat and meat products", *Journal of Food Safety,* vol. 15, no. 2, pp. 91-112.

Solomon, T.P. & Blannin, A.K. 2009, "Changes in glucose tolerance and insulin sensitivity following 2 weeks of daily cinnamon ingestion in healthy humans", *European Journal of Applied Physiology,* vol. 105, no. 6, pp. 969-976.

Solomon, T. & Blannin, A. 2007, "Effects of short-term cinnamon ingestion on in vivo glucose tolerance", *Diabetes, Obesity and Metabolism,* vol. 9, no. 6, pp. 895-901.

Srinivasan, K. 2005, "Spices as influencers of body metabolism: an overview of three decades of research", *Food Research International,* vol. 38, no. 1, pp. 77-86.

Stevenson, R.J. & Yeomans, M.R. 1995, "Does exposure enhance liking for the chilli burn?", *Appetite,* vol. 24, no. 2, pp. 107-120.

Stevenson, R.J. & Prescott, J. 1994, "The effects of prior experience with capsaicin on ratings of its burn", *Chemical Senses,* vol. 19, no. 6, pp. 651-656.

Stevenson, R.J. & Yeomans, M.R. 1993, "Differences in ratings of intensity and pleasantness for the capsaicin burn between chili likers and non-likers: implications for liking development", *Chemical Senses,* vol. 18, no. 5, pp. 471-482.

Suekawa, M., Ishige, A., Yuasa, K., Sudo, K., Aburada, M. & Hosoya, E. 1984, "Pharmacological studies on ginger. I. Pharmacological actions of pungent constitutents, (6)-gingerol and (6)-shogaol", *Journal of Pharmacobio-Dynamics,* vol. 7, no. 11, pp. 836-848.

Szallasi, A. 2005, "Piperine: researchers discover new flavor in an ancient spice", *Trends in Pharmacological Sciences,* vol. 26, no. 9, pp. 437-439.

Szallasi, A. & Blumberg, P.M. 1999, "Vanilloid (Capsaicin) receptors and mechanisms", *Pharmacological Reviews,* vol. 51, no. 2, pp. 159-212.

Tepper, B.J. & Trail, A.C. 1998, "Taste or health: A study on consumer acceptance of corn chips", *Food Quality and Preference,* vol. 9, no. 4, pp. 267-272.

Ueki, S., Miyoshi, M., Shido, O., Hasegawa, J. & Watanabe, T. 2008, "Systemic administration of [6]-gingerol, a pungent constituent of ginger, induces hypothermia in rats via an inhibitory effect on metabolic rate", *European Journal of Pharmacology,* vol. 584, no. 1, pp. 87-92.

Vanschoonbeek, K., Thomassen, B.J., Senden, J.M., Wodzig, W.K. & van Loon, L.J. 2006, "Cinnamon supplementation does not improve glycemic control in postmenopausal type 2 diabetes patients", *Journal of Nutrition,* vol. 136, no. 4, pp. 977-980.

Wadikar, D. & Premavalli, K. 2011, "Appetizer administration stimulates food consumption, weight gain and leptin levels in male Wistar rats", *Appetite,* vol. 57, no. 1, pp. 131-133.

Westerterp-Plantenga, M.S., Diepvens, K., Joosen, A.M.C.P., Bérubé-Parent, S. & Tremblay, A. 2006, "Metabolic effects of spices, teas, and caffeine", *Physiology & Behavior,* vol. 89, no. 1, pp. 85-91.

Westerterp-Plantenga, M.S., Smeets, A. & Lejeune, M.P.G. 2005, "Sensory and gastrointestinal satiety effects of capsaicin on food intake", *International Journal of Obesity,* vol. 29, no. 6, pp. 682-688.

Whiting, S., Derbyshire, E. & Tiwari, B. 2012, "Capsaicinoids and capsinoids. A potential role for weight management? A systematic review of the evidence", *Appetite,* vol. 59, no. 2, pp. 341-348.

Wu, K.L., Rayner, C.K., Chuah, S.K., Changchien, C.S., Lu, S.N., Chiu, Y.C., Chiu, K.W. & Lee, C.M. 2008, "Effects of ginger on gastric emptying and motility in healthy humans", *European Journal of Gastroenterology & Hepatology,* vol. 20, no. 5, pp. 436-440.

Yoshida, T., Yoshioka, K., Wakabayashi, Y., Nishioka, H. & Kondo, M. 1988, "Effects of capsaicin and isothiocyanate on thermogenesis of interscapular brown adipose tissue in rats", *Journal of Nutritional Science and Vitaminology,* vol. 34, no. 6, pp. 587-594.

Yoshioka, M., Imanaga, M., Ueyama, H., Yamane, M., Kubo, Y., Boivin, A., St-Amand, J., Tanaka, H. & Kiyonaga, A. 2004, "Maximum tolerable dose of red pepper decreases fat intake independently of spicy sensation in the mouth", *British Journal of Nutrition,* vol. 91, no. 6, pp. 991-995.

Yoshioka, M., Lim, K., Kikuzato, S., Kiyonaga, A., Tanaka, H., Shindo, M. & Suzuki, M. 1995, "Effects of red-pepper diet on the energy metabolism in men", *Journal of Nutritional Science and Vitaminology,* vol. 41, no. 6, pp. 647-656.

Yoshioka, M., St-Pierre, S., Drapeau, V., Dionne, I., Doucet, E., Suzuki, M. & Tremblay, A. 1999, "Effects of red pepper on appetite and energy intake", *British Journal of Nutrition,* vol. 82, no. 2, pp. 115-123.

Yoshioka, M., St-Pierre, S., Suzuki, M. & Tremblay, A. 1998, "Effects of red pepper added to high-fat and high-carbohydrate meals on energy metabolism and substrate utilization in Japanese women", *British Journal of Nutrition,* vol. 80, no. 6, pp. 503-510.

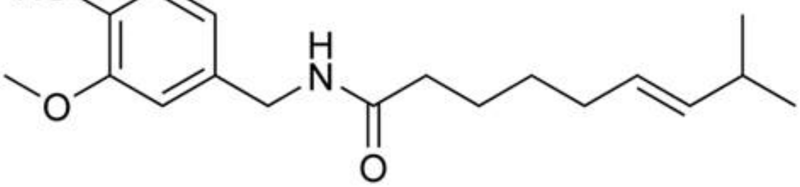
Zandstra, E., de Graaf, C. & Van Trijp, H. 2000, "Effects of variety and repeated in-home consumption on product acceptance", *Appetite,* vol. 35, no. 2, pp. 113-119.

Ziegenfuss, T.N., Hofheins, J.E., Mendel, R.W., Landis, J. & Anderson, R.A. 2006, "Effects of a water-soluble cinnamon extract on body composition and features of the metabolic syndrome in pre-diabetic men and women", *Journal of the International Society of Sports Nutrition,* vol. 3, no. 2, pp. 45-53.

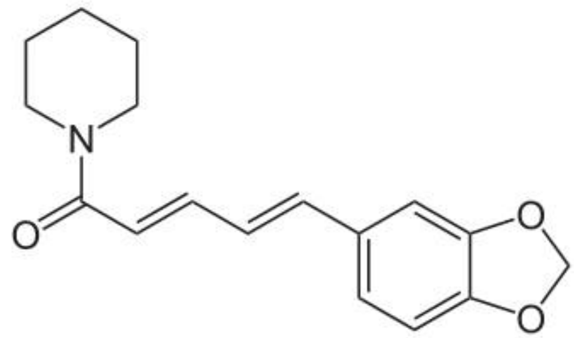
Figure Legends

Figure 1 Chemical structures of capsaicin, piperine, and gingerol have an aromatic ring and alkyl side-chain. Allyl isothiocyanate is an organosulfur compound.

Figure 2. Summary of proposed benefits of pungent spices on health.



Capsaicin



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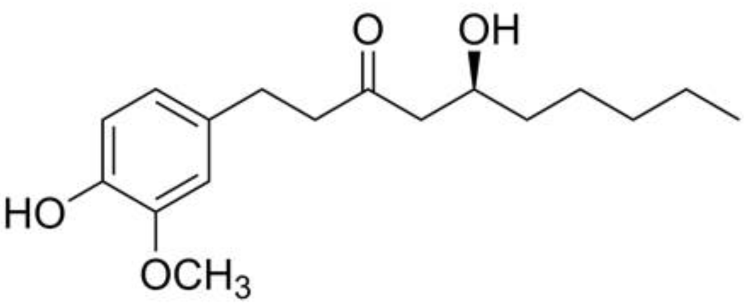

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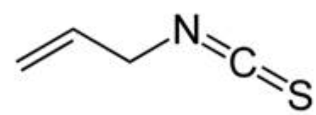
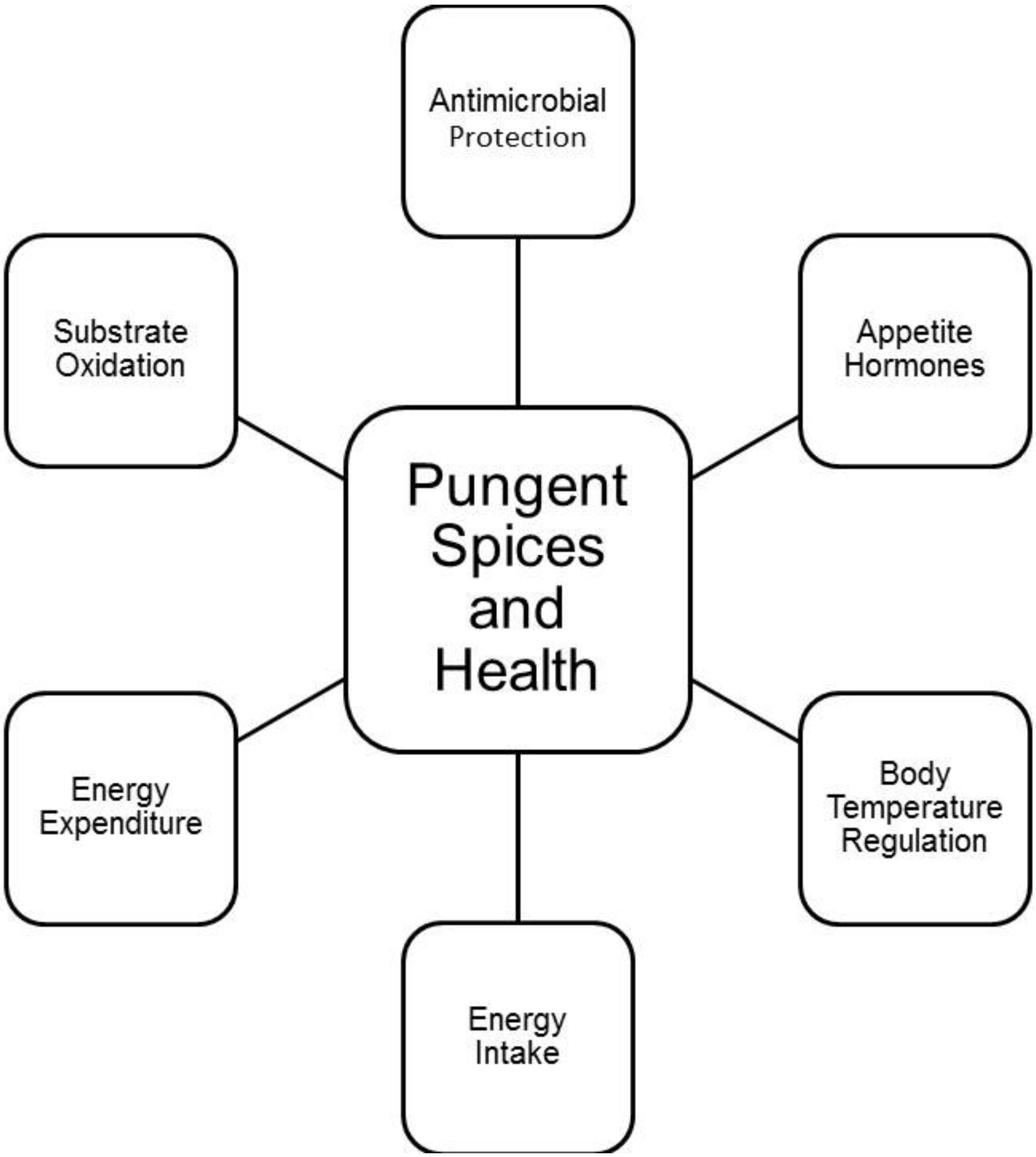


Allyl Isothiocyanate


Antimicrobial Protection
Substrate Oxidation
Appetite Hormones
Pungent Spices and Health
Energy Expenditure
Body Temperature Regulation
Energy Intake