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Effects of a healthy meal course on spontaneous energy intake, satiety and palatability

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Many food components can influence satiety or energy intake. Combined together, these food components could represent an interesting dietary strategy in the prevention and treatment of obesity. The aims of this study were: 1) to determine the effect of a functional food in the form of a healthy meal course on subsequent energy intake and satiety; 2) to verify if it is possible to maintain palatability while preserving the satiating effects of the test meal. Thirteen subjects were invited to eat two lunch sessions: healthy and control meal courses (2090 kJ/meal). Anthropometric and *ad libitum* food intake measurements, and visual analogue scales (VAS) were performed during the two lunch sessions. The healthy main course acutely decreased energy intake during the rest of the meal (− 744 kJ, $P \leq 0{\cdot}0001$) and lipid (− 6 %, $P \leq 0{\cdot}0001$) compared with the control meal. VAS ratings during the course of the testing showed a meal effect for hunger, desire to eat and prospective food consumption ($P \leq 0{\cdot}05$) and a time effect for all appetite sensations ($P \leq 0{\cdot}0001$). VAS scores on hunger ratings were lower for the healthy meal ($P \leq 0{\cdot}05$), whereas fullness ratings were higher shortly after the healthy main course ($P \leq 0{\cdot}05$). The healthy meal produced a slightly higher palatability rating but this effect was not statistically significant. These results suggest that it is possible to design a healthy meal that decreases spontaneous energy intake and hunger without compromising palatability.

Appetite control: Palatability: Energy intake: Macronutrients: Functional food

The obesity epidemic that is prevailing in most countries of the world is imposing a significant pressure towards the search for solutions that can induce a spontaneous negative energy balance. In the field of nutrition, energy restriction of different degrees of severity has been traditionally used to produce this effect. Unfortunately, clinical research and experience have not proven the efficacy of this approach since weight loss is generally a short-term achievement and weight regain is usually observed over time (Wadden *et al.* 1989; Anderson *et al.* 2001). This suboptimal outcome is troublesome for health professionals, particularly dietitians, who have taken advantage in some cases of this reality to become more sensibilized to the idea that an energy deficit induced by diet management cannot be dissociated from the potential of food to promote satiety. In this regard, numerous studies have identified some nutrients and food ingredients that can produce a short-term increase in satiety and/or a spontaneous decrease in energy intake. This literature suggests that a highly satiating food should tend to be characterized by a low lipid content (Lissner *et al.* 1987; Tremblay *et al.* 1989, 1991), a minimal alcohol content (Tremblay *et al.* 1995; Tremblay & St-Pierre, 1996), a preference for low glycaemic index carbohydrates (Ludwig, 2000; Roberts, 2003; Warren *et al.* 2003), a high protein content (Skov *et al.* 1999; Eisenstein *et al.* 2002), a high dietary fibre content (Howarth *et al.* 2001; Pereira & Ludwig, 2001; Koh-Banerjee & Rimm, 2003), a low energy density (Stubbs *et al.* 1995; Bell *et al.* 1998; Rolls *et al.* 1999*a*, 2005), a large food volume (Rolls *et al.* 1998, 1999*b*), an adequate level of vitamins and minerals (Doucet *et al.* 2000; Johnston, 2005), particularly Ca (Zemel *et al.* 2000; Jacqmain *et al.* 2003), and the content of some thermogenic and/or anorectic compounds such as caffeine (Poehlman *et al.* 1985; Tremblay *et al.* 1988; Dulloo *et al.* 1989), capsaicin (Yoshioka *et al.* 2001), Oolong tea (antioxidants) (Rumpler *et al.* 2001) and green tea catechins (Dulloo *et al.* 1999; Berube-Parent *et al.* 2005; Diepvens *et al.* 2005; Westerterp-Plantenga *et al.* 2005). This literature suggests that a highly satiating food that integrates these nutritional properties in one single meal could favour, in an *ad libitum* context, a negative energy balance. This represents a major challenge for the food industry since the development of such meal/menus must reconcile a high palatability level with highly satiating components. This is also an important point since investigations have demonstrated that organoleptic and sensory properties of food tend to significantly alter feeding behaviours and spontaneous energy intake (Drewnowski, 1995; Sorensen *et al.* 2003; Rolls, 2005).

Abbreviations: VAS, visual analogue scale.
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The integration of all these observations emphasizes the relevance of a further step of research that would be closer to the needs of patients subjected to a weight-loss programme. In such a context, the main issue is not the standardization for any single factor potentially influencing energy intake but is rather the testing of palatable menus/meals integrating many satiating food properties to induce a maximal impact on energy intake under conditions that are as representative as possible of free-living conditions. Moreover, it is important to design highly palatable menus aimed at facilitating the spontaneous compliance to a diet of reduced energy content. Therefore, the first aim of this study was to determine the effects of a functional food characterized by healthy and satiating attributes (also referred to as healthy meal course) on subsequent energy intake and satiety for the rest of the meal (dessert) and on total daily energy intake compared with a control main meal course. A second aim of this study was to evaluate the palatability of this healthy meal course as well as to determine the amount of money that subjects would be ready to pay for it.

Subjects and methods

Subjects

Fifteen healthy men volunteered to participate in the present study but two of them were excluded because of their non-compliance to study procedures. The remaining thirteen men were aged 26 (SD 4) years and the main relevant anthropometric characteristics were as follows: body weight 73·2 (SD 8·0) kg; height 1·76 (SD 0·06) m; BMI 23·9 (SD 2·1) kg/m^2. All subjects were non-smokers, did not have any special dietary requirements (e.g. vegetarian), did not take any medication, had a sedentary lifestyle or were moderately physically active (i.e. less than 3 h physical exercise per week) and maintained a stable body weight over the last 3 months preceding the study (±4 kg). In addition, subjects had no previous knowledge of the concept of healthy meal impact on satiety, were not allergic to, nor did they have an aversion to, any of the food ingredients used in the present study. The protocol was approved by the Laval University Ethics Committee and written informed consent was obtained from all subjects.

Testing procedures

The protocol was based on a within subjects, repeated measures design. The subjects were invited to the laboratory on two randomly assigned occasions, separated by a 1-week period, for a 1-h session, during which they were offered a two-course lunch test. Before this session, the subjects had instructions to consume a standardized breakfast at home 4 h before the lunch test. This breakfast was provided by the research team and consisted of white bread, butter, peanut butter, cheddar cheese and an orange. Its energy content was 3066 kJ (44, 42 and 14 % from carbohydrate, fat and protein, respectively). Until arrival at the laboratory, subjects were instructed not to eat or drink anything except water if necessary.

After the anthropometric measurements were performed, compliance to the standardized breakfast was verified. The subjects also completed a four-question visual analogue scale (VAS) (Hill & Blundell, 1986) to obtain ratings on a 150 mm scale for hunger, desire to eat, fullness and prospective food consumption (quantity of food that the participants thought they could eat) as well as food appreciation after the meal. The main course (healthy meal or control) of the lunch was then served and had to be entirely consumed within a 30-min period. Immediately after finishing this course, VAS on appetite sensations and the appreciation of the meal were completed. A questionnaire on general features of the meal, the willingness to buy the food at a grocery, the amount of money to be ready to be paid for a similar meal and other comments was also completed (Appendix 1). Approximately 10 min after finishing the first course, the subjects were offered a dessert (second course) that they could eat *ad libitum* within a 15-min period. Just before serving the dessert, VAS on appetite sensations were completed. Upon finishing the dessert, subjects again completed VAS on appetite sensations and appreciation of the dessert. After the lunch, subjects were instructed not to eat during the next 3 h, during which they had to complete VAS on appetite sensations every 30 min.

Thereafter, they were free to eat but they had to complete a dietary record to evaluate food and energy intake for the remainder of the day. To ensure a realistic approximation of the energy consumed, subjects were instructed to be as precise as possible by indicating the source, quantities, place of consumption (out or at home) and consumption time. After completion, a nutritionist revised each record with each subject to validate the information obtained with the dietary record.

Each food, including water, served during each course of the meal was weighed before and after consumption with a food scale (Weigh Tronix, VI-4000, Acculab) at the nearest 0·1g to determine energy and macronutrient intakes as well as the weight of food consumed. Total daily energy intake was calculated by summing the energy content of breakfast, the measured intake at lunch time and the reported intake for the rest of the day. The calculation of energy and macronutrient content of the food (measured and reported) was performed using the Canadian Nutrient File (Health and Welfare Canada, 1997).

Two lunch sessions: healthy and control main courses

The two lunch sessions tested included two courses each, i.e. main and dessert. The first course was a main course with a standardized energy content characterized by different satiating, organoleptic and sensory properties (healthy or control main course). The second one consisted of a dessert that was served *ad libitum*. The dessert was provided by a caterer and consisted of a chocolate mousse cake containing 1910 kJ/100 g (48 %, 44 % and 8 % from carbohydrate, lipid and protein, respectively). In other words, the main course was the only part of the meal that differed between the two lunch sessions.

The satiating ingredients combined in the healthy meal course were selected based on their known individual impact on short-term satiety and/or energy intake (see p. 584 for references). Accordingly, the healthy meal course was designed with a reduced fat content, an increased protein and fibre content, a lower energy density, the addition of some spicy ingredients, such as capsaicin, and with a higher volume. The list of ingredients, the nutritional content, the price of the two main courses, i.e. chicken stir-fry and fettuccini carbonara, are presented in Table 1. The chicken stir-fry main course was specially designed in order to increase satiety (healthy main course) whereas the fettuccini carbonara course was considered as a usual reference dish (control main course).

Anthropometric measurements

Body weight and height were measured to the nearest 0·1 kg and 0·1 cm, respectively. BMI was calculated as body weight divided by height squared (kg/m^2). Furthermore, waist circumference was measured to 0·1 cm accuracy using a Gulick fibreglass anthropometric tape (M-22C; Creative Health Products, Ann Arbor, MI, USA).

Statistical analysis

Data were analysed by using SAS-PC for Windows (version 9.1; SAS Institute, Cary, NC, USA) and expressed as means and standard deviations. Statistical significance was set at $P < 0·05$. Food intake (g), energy intake (kJ) and the percentage of macronutrients were analysed for the standardized breakfast, the two courses (main and dessert) of the lunch and the rest of the day following the lunch. These variables and total daily intake were compared between the two lunch sessions by using a paired *t* test. VAS ratings during the course of the session were analysed by using a two-way ANOVA for repeated measures in order to test time, meal and time × meal interaction effects. Thereafter, a paired *t* test was used to analyse the different VAS ratings.

Results

Energy and macronutrient intakes

Mean energy intake at different times over the day for both lunch sessions is presented in Table 2. Energy intake was significantly lower (−744 (SD 635) kJ, $P \leq 0·001$) after the lunch dessert (second course) with the healthy main course (chicken stir-fry) compared with the control main course (fettuccini carbonara). Since the main course of each meal had a similar energy content, this difference also represented the decrease in energy intake for the whole meal at lunch in the satiating condition. When comparing energy intakes from the food records, subjects also tended to consume less energy after the healthy satiating lunch session than in the control lunch session but this difference was not statistically significant (−1028 (SD 2943) kJ, $P > 0·05$). Total daily intake also tended to be lower for the chicken stir-fry lunch session compared with the control lunch session (−1756 (SD 3064) kJ, $P = 0·067$).

Table 1. Pictures, lists of ingredients, nutritional values and costs of the healthy meal (chicken stir-fry) and the control meal (fettuccini carbonara) courses

Chicken stir-fry		Fettuccini carbonara	
Ingredients: Chicken strips, ginger, green onion, soy sauce, orange juice, orange zest, garlic, bean sprouts, chopped green cabbage, chopped red pepper, chopped carrot, broccoli rosettes and whole wheat spaghetti		Ingredients: Bacon, spaghetti, parmesan cheese, white wine, finely chopped parsley, olive oil, egg, garlic and white pepper	
			
Weight/portion (g)	400	Weight/portion (g)	185
Energy content	2090 (SD 21) kJ	Energy content	2090 (SD 21) kJ
Energy density (kcal/g)	1·25	Energy density (kcal/g)	2·7
Carbohydrate (%)*	56	Carbohydrate (%)	41
Lipid (%)	11	Lipid (%)	38
Protein (%)	32	Protein (%)	18
Alcohol (%)	0	Alcohol (%)	4
Fibre (g)	9	Fibre (g)	1·5
Portion cost† (Canadian $)	2·00	Portion cost (Canadian $)	1·30

* Percentage of energy intake.
† Prices were based on seasonal availability of the ingredients used.
For details of subjects and procedures, see pp. 585–586.

Table 2. Energy intakes during the two lunch sessions‡
(Mean values and standard deviations)

Variables	Healthy meal: chicken stir-fry Mean	SD	Control meal: fettuccini carbonara Mean	SD
Lunch dessert (second course)				
Energy (kJ)	2362	1342	3106***	1434
Amount of food consumed (g)	124	70	163***	75
Water (g)	154	131	210	123
Carbohydrate (%)	48		48	
Lipid (%)	44		44	
Protein (%)	8		8	
Alcohol (%)	–		–	
Total lunch intake: Main course + dessert				
Energy (kJ)	4427	1363	5154**	1476
Amount of food consumed (g)	565	75	366***	79
Carbohydrate (%)	52	1	45***	1
Lipid (%)	27	4	42***	1
Protein (%)	20	3	12***	1
Alcohol (%)	–		1	1
Food record (intake during the rest of the day)				
Energy (kJ)	4932	1659	5961	3804
Carbohydrate (%)	48	11	46	13
Lipid (%)	31	10	35	9
Protein (%)	19	8	17	5
Alcohol (%)	3	6	2	5
Total daily intake				
Energy (kJ)	12 394	2533	14 149†	3833
Carbohydrate (%)	48	5	45*	7
Lipid (%)	33	4	39***	4
Protein (%)	18	3	14*	3
Alcohol (%)	1	2	1	2

df 12, mean values were significantly different from those for fettuccini carbonara: $^{*}P\leq 0{\cdot}05$; $^{**}P\leq 0{\cdot}01$; $^{***}P\leq 0{\cdot}001$; †$P=0{\cdot}067$.
‡ % indicates the percentage of energy intake.
For details of diets and procedures, see pp. 585–586.

Total macronutrient intakes were significantly different between the two lunch sessions. After the healthy meal course session, the percentage of energy intake as carbohydrate and protein was significantly higher compared with the control main course (+3·3 (SD 4·8) and +3·2 (SD 4·1) %, $P<0{\cdot}05$, respectively). In contrast, the proportion of energy intake from lipid was significantly lower after the healthy meal course (−6·1 (SD 3·5) %, $P\leq 0{\cdot}0001$). The differences in total daily macronutrient intake were mainly attributable to the composition of the healthy meal course.

Visual analogue scale ratings

Subjective ratings for hunger, fullness and prospective food consumption are presented in Fig. 1. Subjective ratings for desire to eat are not presented since they had a similar pattern to VAS ratings for hunger. All VAS ratings were influenced by a significant time effect ($P\leq 0{\cdot}01$). There was also a significant meal effect for hunger, desire to eat and prospective food consumption ($P\leq 0{\cdot}05$). However, there was no significant time by meal interaction. There was no significant difference in ratings before each lunch session, which indicates similar baseline lunch sessions. The ratings for hunger and prospective food consumption were significantly lower immediately after the chicken stir-fry main course lunch compared with the control main course ($0{\cdot}001 \leq P\leq 0{\cdot}01$), whereas those for fullness were significantly higher after the healthy meal course ($0{\cdot}001 \leq P\leq 0{\cdot}01$). The ratings for hunger remained significantly lower after the healthy meal course for the duration of the lunch and the three postprandial hours ($P\leq 0{\cdot}05$). Feelings of fullness did not differ significantly during the same period between the two conditions. Prospective food consumption was significantly lower after the healthy meal course for as long as 30 min after the lunch ($P\leq 0{\cdot}05$). After this time, the ratings were still lower but the difference was no longer significant, except for the 150-min rating ($P\leq 0{\cdot}05$).

Palatability

The VAS ratings for appreciation of the meal were slightly higher for the chicken stir-fry main course (116 (SD 30) min) immediately after its ingestion compared with the control main course (105 (SD 25) min) but this difference was not statistically significant ($P=0{\cdot}23$). After the dessert, ratings for appreciation of the meal were again higher for the healthy meal session (113 (SD 27) min) compared with the control course food session (106 (SD 36) min) but this difference was also non-significant ($P=0{\cdot}33$).

General perception of the meal

The questionnaire documenting the general perception of the meal indicated that subjects appreciated both meals. The chicken stir-fry meal was appreciated because of the diversity, quality, taste, colour and freshness of the ingredients used. The portion size of this meal was found to be generous in comparison with the portion size of the control meal, which was perceived as undersized. This was concordant with the fact that more time was needed to consume the chicken stir-fry compared with the fettuccini carbonara course (difference of 9·31 (SD 1·61) min). Finally, this questionnaire revealed that subjects were willing to pay Canadian $2·05 (SD 0·38) more for a meal similar to the healthy meal course compared with a meal similar to the control main course.

Discussion

In accordance with the first law of thermodynamics, the dietary management of obesity over the last decades has been focused on energy-restricted diets aimed at achieving a short-term energy deficit (National Institutes of Health, 1998). Accordingly, it is not surprising that such approaches were found to be successful to induce body-weight loss in the short term in most individuals (Wadden *et al.* 1989; Wadden, 1993; Anderson *et al.* 2001). However, when the outcome is examined on a long-term basis, it seems that the initial success gives way to frustration, since weight regain is often the endpoint of the intention to treat obese individuals (Wadden *et al.* 1989; Anderson *et al.* 2001). This impels dietitians and food specialists to reconsider the mode of treatment in order to reconcile the maintenance of a negative energy balance state with healthy food practices.

The identification of dietary compounds that can increase satiety and/or decrease spontaneous energy intake have raised optimism regarding the development of healthy satiating foods that might have the potential to improve compliance to a negative energy balance. As discussed earlier, the main

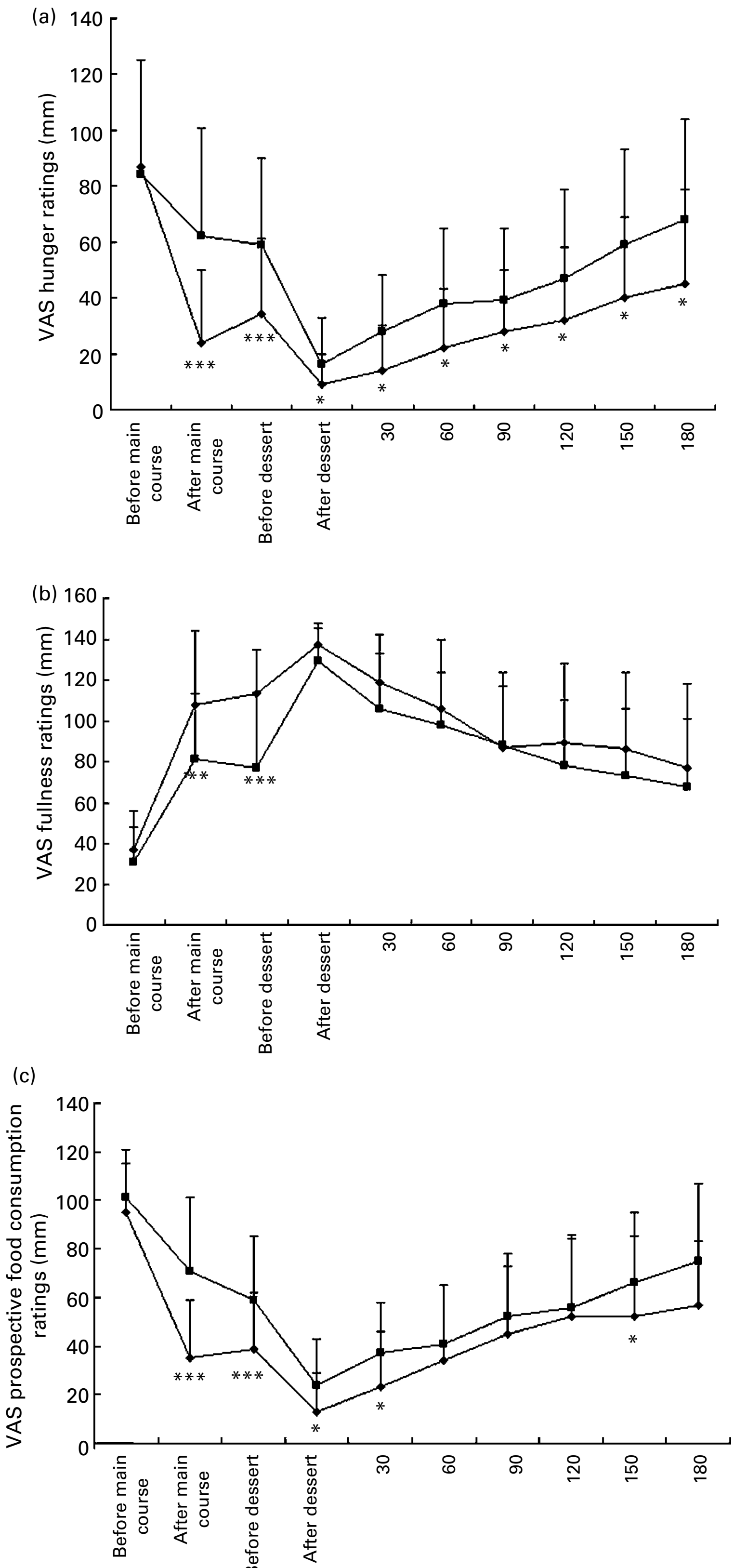

Fig. 1. Visual analogue scale (VAS) ratings for (a) hunger, (b) fullness and (c) prospective food consumption in the two lunch sessions: healthy meal (–◆–; chicken stir-fry) and control meal (–■–; fettuccini carbonara). Values are means and standard deviations, df 12. Mean values were significantly different from those for fettuccini carbonara: *$P \le 0.05$; **$P \le 0.01$; ***$P \le 0.001$. For details of diets and procedures, see pp. 585–586.

issue thus becomes a food planning strategy that integrates the maximal number of food-related satiating properties to reduce energy intake without the perception of undereating and/or restriction. As a first approach evaluating this issue, we designed menus with the goal of promoting satiety at a fixed energy intake. We also assessed the degree of compatibility between satiety-promoting food and palatability, and the degree of readiness to pay for such a food concept.

In agreement with the previously described food/nutrient properties known to influence appetite control (Drapeau & Tremblay, 2000), the healthy meal course tested in the present study, i.e. the chicken stir-fry, was characterized by a reduced fat content, an increased protein and fibre content, the addition of capsaicin and a lower energy density and a higher volume compared with the reference control course. Immediately after its ingestion, the levels of perceived feelings of hunger were decreased, which was consistent with the significant subsequent decrease in energy intake at dessert, which was offered *ad libitum*. Interestingly, the increased state of satiety induced by the chicken stir-fry course was still observed for several hours after lunch time and was associated with an additional decrease in energy intake at dinner time. Taken together, these repeated decreases resulted in a cumulative reduction in energy intake of 1756 kJ/d. Such a change over two meals is significant and could theoretically represent a body weight loss of about 0·5 kg/week. This corresponds to a typical energy deficit and body-weight loss generally targeted in obesity intervention (National Institutes of Health, 1998).

Because the two meals were different in appearance, smell, texture, taste, water content, volume and that all these factors have been shown to influence energy intake (Rolls *et al.* 1998; Sorensen *et al.* 2003), it is difficult to precisely identify which characteristic of the meal caused the expected decrease in spontaneous energy intake. In this regard, the main aim of the present study was not to describe the contribution of each specific feature of the healthy meal course but was rather to design a course integrating these properties in a palatable menu to promote a negative energy balance compared with a standard meal. From a clinical standpoint, this study suggests that, in the short term, a substantial decrease in spontaneous energy intake could be reached with the consumption of healthy menus without any compromise on perceived pleasantness of food. The next step would be to perform a longer study in the obese population with other healthy satiating and control meals to confirm and extend these results.

Since pleasure and satisfaction seem to be important determinants for the adherence to many healthy practices (Esch & Stefano, 2004), such as healthy food habits, it is clear that food palatability should be viewed as an important criterion to be considered in the design of healthy foods. In the present study, it is encouraging to note that the chicken stir-fry course received an appreciation score that was equal to or slightly higher than the palatable fettuccini carbonara control course. This suggests that it is realistic and feasible to achieve a highly satiating food profile and palatability in a context where a negative energy balance is a desired outcome.

Another important feature of healthy meals, be it in the field of obesity or in regard to other health-related issues, is related to the cost issue (Horgen & Brownell, 2002). As indicated in Table 1, the cost of the ingredients of the chicken stir-fry exceeded by Canadian $0·70 the cost of those included in our fettuccini carbonara recipe. However, the appreciation questionnaire completed by the subjects indicated that they would have paid Canadian $2·05 more for the chicken stir-fry than for the fettuccini carbonara course. Again, these observations are encouraging since they suggest that industrial food producers might experience success in their endeavour to achieve both profitability and the production of healthy foods.

The results of the present study have shown that a healthy meal course can successfully improve satiety and reduce subsequent energy intake. The current data also suggest that it is possible to take advantage of these properties without compromising short-term appetite control. Finally, the opinion of our subjects indicated a readiness to pay more money for these foods compared with the additional cost of their ingredients.

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Appendix 1

Questionnaire reflecting appreciation of the meal, willingness to buy at a grocery and amount of money subjects were willing to pay for a similar meal and other comments.

1. Avez-vous aimé ce plat? OUI/NON

   (Did you like this meal? YES/NO)

2. Pourquoi?

   (Why?)

3. Acheteriez-vous ce produit à l'épicerie? OUI/NON

   (Would you consider buying this product at a grocery? YES/NO)

4. Combien payeriez-vous pour ce produit? Canadiens $)

   (How much would you be willing to pay for a product like this? Canadian $

5. Autres commentaires appréciés s.v.p.

   (Other comments please)