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Nature and Cognitive Perception of 4 Different Breakfast Meals Influence Satiety-Related Sensations and Postprandial Metabolic Responses but Have Little Effect on Food Choices and Intake Later in the Day in a Randomized Crossover Trial in Healthy Men

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Abstract

Background: Regular breakfast consumption is associated with better health status and healthier food intake throughout the day, but this association is a complex interaction of several factors.

Objective: This study aimed to investigate the effect of nutritional and cognitive-perceived characteristics of breakfast on metabolic and behavioral variables related to food intake.

Methods: The study was a randomized, crossover, controlled trial, with 4 experimental conditions consisting of 3 iso-energetic breakfasts and 1 energy-free control meal. Breakfasts had similar nutritional profiles but differed for glycemic index (GI), glycemic load (GL), and perceived healthiness, satiety, palatability, or energy content. Fifteen healthy normal-weight men [means ± SDs; age: 24 ± 2 y; body mass index (BMI; kg/m^2) 23.4 ± 1.6] underwent each experimental condition in random order during 4 different weeks, separated by $\geq$1-wk washout. On the third day of each intervention week, postprandial blood variables (with insulin as primary outcome), satiety ratings, and food intake during an ad libitum lunch consumed 4 h after breakfast (secondary outcomes) were measured for each experimental condition.

Results: A main effect of time, treatment, and time × treatment was found for postprandial insulin, glucose, and nonesterified fatty acids ($P < 0.001$ for all) after having the 3 iso-energetic breakfasts or the energy-free control one. Postprandial satiety was similar for the 3 energy-containing breakfasts, but higher when compared with the energy-free control ($P < 0.001$). No difference in energy intake was observed for the ad libitum lunch, whereas prolonged breakfast skipping was compensated by an increase (around +10%) in the average energy intake during the rest of the day, resulting in no differences in the total daily energy intake among the 4 conditions.

Conclusions: Although other advantages might exist for breakfasts based on low-GI/low-GL foods, our findings support the hypothesis that minor differences in nutritional and perceived characteristics of breakfast are of limited importance regarding medium-term energy intake in healthy men. This trial was registered at clinicaltrials.gov as BRNN-014 NCT02516956. *J Nutr* 2018;148:1536–1546.

Keywords: breakfast, satiety, appetite, food choice, glycemic index, glycemic load, metabolic response, energy intake, lunch

Introduction

A large body of evidence suggests that regular breakfast consumption is associated with better health (1–3). Nevertheless, a high prevalence of breakfast skipping is observed worldwide (4). Breakfast skipping is often used as an easy strategy to control body weight by cutting calories (5). Indeed, some experimental evidence indicates that skipping breakfast might result in lower energy intakes in lean individuals (6–8). However, a large number of observational studies demonstrate that those who habitually have breakfast generally show a lower BMI than breakfast skippers (9, 10), and that the amount of calories from

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breakfast does not significantly increase the risk of exceeding the total daily recommended energy supply (2). This could be partially due to a redistribution of daily energy intake, so that if more energy is consumed at breakfast less energy is consumed later in the day (9). Epidemiologic evidence also shows favorable effects of breakfast and some of its components (e.g., whole grain) on risk factors of chronic diseases such as cardiovascular diseases and type 2 diabetes, including lipid profile, impaired glucose tolerance, and overweight or obesity (11–13). In addition, breakfast can affect the overall quality of the diet according to its nutrient composition. For example, cross-sectional evidence showed that subjects who regularly consume breakfast tend to have higher intake of fiber and calcium and lower intake of fats and total calories (14), whereas skipping breakfast can reduce the probability of meeting the RDAs for many micronutrients (15, 16). In general, breakfast habits are rather variable, including carbohydrates with different glycemic index (GI) as well as different amounts of proteins and fats, all elements possibly related to effects on satiety. In this context, it has been proposed that consumption of low-GI foods at breakfast may reduce food intake in the later meals, probably through their ability to increase satiety (17–19). Although breakfast seems to be associated with a better control of energy balance, understanding this association is complicated by the multifaceted interaction of several factors resulting in food intake, such as body homeostasis, lifestyle, and cultural and social habits. Moreover, palatability or perceived health characteristics of food might also play a role. Indeed, most of the theories on the regulation of food intake propose 2 parallel systems—homeostatic and hedonic—interacting with food consumption (20, 21). The former drives adequate nutrition by increasing the motivation to eat after depletion of nutrients and/or energy stores, according to hypothalamus-regulated hunger, satiety, and appetite mechanisms as well as the levels of systemic mediators such as leptin and ghrelin (22). On the other side, the hedonic system can influence caloric intakes exceeding requirements by increasing the desire to consume highly palatable foods (23). The cross-talk between metabolic and emotional-cognitive regulatory systems determines food intake (24), integrating food-related sensory information and reward-related affective responses with satiety signals produced by the gastrointestinal tract to set up a mental representation of food (25). For all these reasons, there is an increasing interest in motivational and decisional aspects of food choices and how food characteristics and metabolic responses are able to influence them in determining eating behaviors.

In this framework, the present study aimed to investigate the homeostatic-cognitive system affecting energy balance by exploring the effect of modifications in nutritional composition and perceived characteristics of breakfast on metabolic and behavioral variables related to food intake. For this purpose, we tested the effect of breakfast meals differing in nutritional profiles and perceived healthiness, palatability, satiety, and energy content on *1)* metabolic profile of hormones and substrates, *2)* feelings of hunger and satiety, *3)* food choices during a following meal, and *4)* compensatory responses for energy consumed over the week.

Methods

Participants. Volunteers were recruited through advertisements posted in all departments of the University of Parma. Eligible participants were healthy men, aged >18 and <30 y, with normal [BMI (kg/m^2) >20.0 and <25.0] and stable body weight (less than ±5% change) in the 3 mo before the study, nonsmokers, not taking medication, and with a moderately active lifestyle. In addition, volunteers should have been habitual breakfast eaters (i.e., consuming every day an energy-containing meal composed by at least a food or an energy-containing beverage, such as a fruit juice or an orange squeeze), not following a specific diet, and without any known food allergy, as assessed by a pre-enrollment interview.

Fifteen healthy young men participated in the study (means ± SDs; age: 24 ± 2 y; BMI: 23.4 ± 1.6). All volunteers gave their informed written consent before enrollment. The participant flow diagram for the intervention is shown in **Supplemental Figure 1** (Consolidated Standards of Reporting Trials—CONSORT 2010 flow diagram).

Study design and procedures. The study was a randomized, crossover, and controlled trial, with 4 experimental conditions consisting of different breakfast meals assigned in a random order. Block randomization of the breakfast order was achieved through the use of a computer-generated scheme. Volunteers consumed each of the 4 breakfast meals throughout 4 different weeks, separated by a ≥1-wk washout. At recruitment and at the beginning of each experimental week, volunteers were provided with packages of all the foods they should consume at breakfast according to their intervention sequence. Participants were instructed to have the assigned breakfast every morning at ∼0800, whereas no other dietary or lifestyle indications were provided. The third day of every experimental week, i.e., the Wednesday, was chosen as the test day. On the evening before each test day, participants were instructed to have the same free-choice standard dinner and to avoid strenuous activities thereafter. Volunteers arrived fasting at the clinic at 0730 on the test day. The breakfast period lasted 15 min and appetite and satiety ratings and blood samples were taken before (fasting) and after breakfast consumption according to the experimental plan. At 1200 volunteers were served an ad libitum standard lunch, lasting 30–60 min with participants left eating alone. The study design and experimental plan are reported in **Figure 1**.

The study was conducted in accordance with the Declaration of Helsinki and the Ethics Committee of Parma (Italy) approved the protocol. The trial was registered at the US NIH on clinicaltrials.gov as BRNN-014 NCT02516956.

Breakfast meals. The 4 breakfast meals have been previously described for their composition and perceived characteristics by Rosi and colleagues (26). Briefly, meals were composed of foods that are commonly consumed at breakfast in Italy (2). The control breakfast (F-CTRL) was an energy-free meal consisting of a cup of decaffeinated tea, comparable with a fasting condition. The 3 experimental breakfasts included a cup of semi-skimmed milk, an apple, and 3 different "cereal-based chocolate-containing" foods. The foods were white bread with chocolate hazelnut spread (BR-BREAD), muesli with dark chocolate chips and nuts (BR-MUESLI), and chocolate-flavored puffed rice (BR-RICE). All participants were provided with the same quantity of food and had to consume the whole breakfast provided.

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Supplemental Tables 1 and 2 and Supplemental Figure 1 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/jn/.

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Abbreviations used: BR-BREAD, breakfast with bread with chocolate hazelnut spread, semi-skimmed milk, and an apple; BR-MUESLI, breakfast with muesli with dark chocolate chips and nuts, semi-skimmed milk, and an apple; BR-RICE, breakfast with chocolate-flavored puffed rice, semi-skimmed milk, and an apple; F-CTRL, fasting control treatment; GI, Glycemic Index; GL, glycemic load; GLP-1, glucagon-like peptide-1; iAUC, incremental area under the curve; NEFA, nonesterified fatty acid; VAS, Visual Analog Scale.

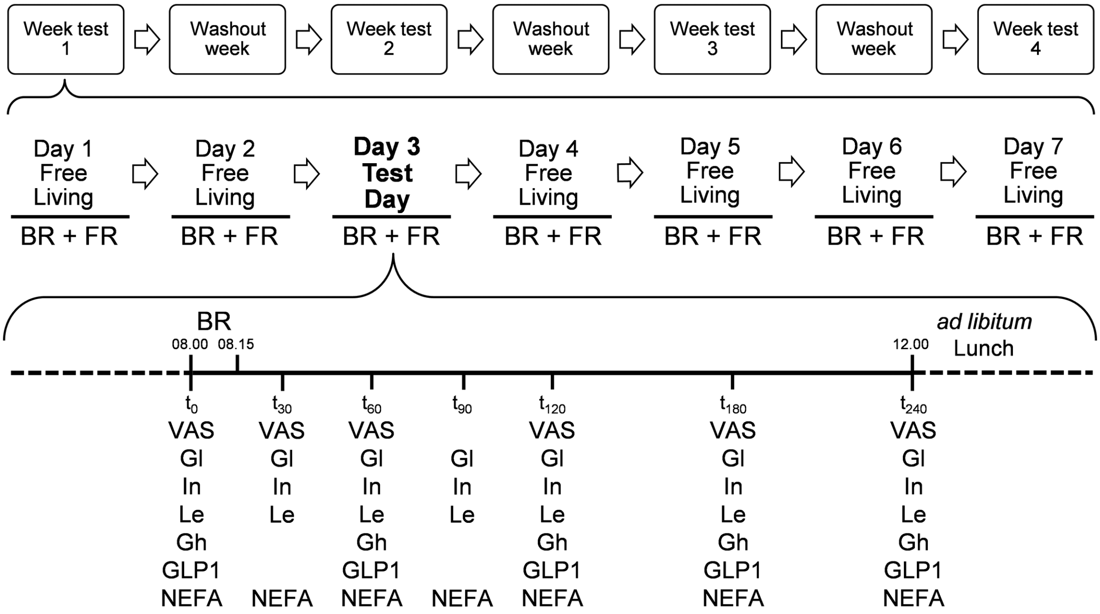

FIGURE 1 Study design and schedule of experimental procedures. BR, breakfast; FR, food record; Gh, ghrelin; Gl, glucose; GLP-1, glucagon-like peptide-1; In, insulin; Le, leptin; NEFA, nonesterified fatty acid; t, time; VAS, visual analog scales for appetite and satiety.

BR-BREAD, BR-MUESLI, and BR-RICE were iso-energetic and similar for protein content, whereas BR-MUESLI was slightly higher in fiber than either BR-BREAD or BR-RICE. BR-BREAD and BR-MUESLI were similar for total carbohydrate, sugar, and lipid profiles, whereas BR-RICE had a lower lipid and higher carbohydrate and sugar content. Moreover, BR-BREAD and BR-MUESLI had similar meal GI (<55) and glycemic load (GL; around 20 g glucose equivalents), calculated on the basis of the GI of meal ingredients (27), which was lower than BR-RICE (GI >55 and GL around 40 g glucose equivalents). Meal ingredients, energy, and nutrient values are shown in **Table 1**. Finally, the 4 breakfast meals presented some differences in their perceived characteristics (26). In brief, participants evaluated the 4 breakfasts before consumption through a 7-point Likert scale (1 = not at all; 7 = extremely), reporting how much they considered the entire meal healthful, palatable, satiating, and energetic. The 3 test breakfasts did not differ for palatability, whereas BR-MUESLI was perceived as the healthiest and BR-BREAD as the most energetic. Conversely, F-CTRL was perceived as the least satiating, palatable, and energetic (Table 1).

Blood sampling and laboratory analyses. Blood samples were collected through a 3-way tap intravenous cannula from the antecubital region of the arm, at baseline and ≤ 4 h after consuming breakfast. Sample timing for each marker is reported in Figure 1. At each collection time, the first milliliter was discarded to avoid contamination with the saline solution used to maintain patency. Blood was drawn into different tubes (Trust BD Vacutainer) depending on metabolic parameter. Samples were centrifuged ($2000 \times g$, 10 min, 20°C) and serum or plasma stored (−80°C) for subsequent analysis. Plasma glucose concentration was determined by an automated analyzer (YSI 2900 Biochemistry Analyzer, YSI Incorporated); the remaining markers were analyzed by high-sensitivity ELISA kits with the use of serum (insulin, from D.B.A. Italia Srl; leptin, from Merck Millipore SpA) or plasma (total ghrelin, from Tema Ricerca; glucagon-like peptide-1 (GLP-1) (active), from Tema Ricerca; nonesterified fatty acid (NEFA), from Kardia Srl).

Appetite and satiety ratings after breakfast consumption. A self-reported questionnaire was completed at baseline and every 30 min up to 4 h after breakfast consumption, as shown in Figure 1. The questionnaire had 2 components: hunger (appetite) and fullness (satiety). Subjective appetite and satiety profiles were rated by answering the question "How hungry do you feel right now?" and "How full do you feel right now?" through 100-mm Visual Analog Scales (VASs) (28). VASs were anchored by "not at all" on the left (0 mm) and "extremely" on the right (100 mm). At each time point, participants were instructed to mark the 100-mm line at the point that best represented their degree of hunger and fullness, respectively. Ratings were scored by measuring the distance (to the closest millimeter) from the left anchor to the point where the mark intersected the line.

Ad libitum lunch. Four hours after breakfast, after the last blood sampling, participants were left free to consume an ad libitum lunch. Foods were prepared on the same day and served as a buffet, which was identical in type and amount for every intervention condition. The ad libitum lunch consisted of 4 different dishes, with a 2 × 2 design based on nutritional and health-perceived characteristics. In relation to the nutritional composition, the 4 dishes were classified as protein-based (salad with ham and cheese, and chicken nuggets) or carbohydrate-based (pasta with vegetables, and pizza with fries). In addition, the 4 dishes were classified as healthy (pasta with vegetables, and salad with ham and cheese) or unhealthy (pizza with fries, and chicken nuggets), based on a former evaluation of healthiness perception of the same meals (26). Energy content, macronutrient values, and experimental categories of the test dishes are presented in **Supplemental Table 1**. Each course was offered in excess of the estimated intake. Pasta and salad were individually served to each participant in large serving bowls, whereas trays were used for pizza and nuggets. Participants were instructed to eat what and how much food they wished until feeling "comfortably full and satisfied". Double weighing of food (before and after consumption) was performed to evaluate food choices, energy, and macronutrient intakes of lunch.

Dietary assessment over the week. Diets of participants were assessed for the whole week during each experimental week. A 7-d weighed food diary was used to collect data for all foods and beverages consumed. Immediately after enrollment, participants were trained by a nutritionist in the use of the food diary. Participants were asked to provide a complete description of all foods and beverages consumed during the day, describing recipes and methods of preparation, and/or noting the brand of manufactured products. Participants were also requested to record the weight of each food/beverage consumed by weighing the product or, if not possible, by evaluating the portion size through standard household measures and a food atlas (29). Time and place of consumption were also specified for all meals.

TABLE 1 Ingredients, nutritional composition, and perceived characteristics by healthy young men of the 4 breakfast meals[1]

	BR-BREAD	BR-MUESLI	BR-RICE	F-CTRL
	Semi-skimmed milk (125 mL), apple (100 g), white bread (45 g) with chocolate hazelnut spread (15 g)	Semi-skimmed milk (150 mL), apple (150 g), muesli with dark chocolate chips and nuts (40 g)	Semi-skimmed milk (150 mL), apple (150 g), chocolate-flavored puffed rice (50 g)	Tea, decaffeinated (125 mL)
Ingredients				
Energy, kcal	332	328	331	—
Protein, g	9.5	9.4	8.2	—
Fat, g	11.2	11.1	4.2	—
Carbohydrate, g	48.5	48.3	66.9	—
Sugars, g	30.6	33.8	43.4	—
Dietary fiber, g	3.9	5.4	4.5	—
Nutritional composition				
Glycemic index	45	47	57	—
Glycemic load (g glucose eq.)	21.8	22.7	38.1	—
Perceived characteristics				
Healthiness	4.5 ± 0.2^{ab}	5.4 ± 0.2^{a}	5.1 ± 0.2^{ab}	3.3 ± 0.5^{b}
Satiety	5.5 ± 0.2^{a}	4.9 ± 0.3^{a}	5.3 ± 0.2^{a}	1.2 ± 0.1^{b}
Palatability	5.5 ± 0.2^{a}	5.1 ± 0.2^{a}	5.1 ± 0.3^{a}	1.9 ± 0.3^{b}
Energy content	5.8 ± 0.2^{a}	4.7 ± 0.3^{b}	4.8 ± 0.3^{b}	1.2 ± 0.1^{c}

[1] Nutritional values of breakfast meals were calculated from the nutritional composition of each ingredient. Perceived characteristic values are mean scores ± SEMs, $n = 15$, registered by a 7-point Likert scale (1 = not at all; 7 = extremely). Labeled means in a row without a common superscript letter differ, $P < 0.05$ (nonparametric Friedman test with post hoc pairwise comparisons). Adapted with permission from reference 26. BR-BREAD, breakfast with bread with chocolate hazelnut spread, semi-skimmed milk, and an apple; BR-MUESLI, breakfast with muesli with dark chocolate chips and nuts, semi-skimmed milk, and an apple; BR-RICE, breakfast with chocolate-flavored puffed rice, semi-skimmed milk, and an apple; eq., equivalents; F-CTRL, fasting control treatment.

The accuracy of the information registered in the food diary was checked twice by a nutritionist in the presence of the participant, on the third and on the last day of each experimental week. Daily intake of energy and macronutrients was calculated by linking food and beverage consumption with the food database of the European Institute of Oncology (30) through a Microsoft Access application.

Statistical analysis. The primary outcome was the postprandial insulin response, considering both the reported major effect of insulin on satiety and the central role of insulin in the homeostatic regulation of metabolism of energetic substrates. Secondary outcomes were postprandial glucose, circulating NEFA, hormones related to calorie intake regulation, and subjective ratings of hunger and satiety. Based on published data on postprandial incremental areas under the curves (iAUCs) of insulinemic responses after breakfasts with different GI (31), a minimum of 4 subjects was required to ensure a power >80% with $\alpha = 0.0167$ for a Bonferroni-corrected crossover design with 3 conditions (i.e., energy-containing breakfasts only), while a number of 12 subjects was required for 4 conditions (i.e., including the control breakfast) with $\alpha = 0.0125$. Considering the eventuality of 20% dropout, to be on the conservative side, an enrollment of 15 volunteers was established as appropriate.

Data are presented as means ± SEMs of 15 independent measurements in response to each breakfast: *1)* biomarkers related to appetite; *2)* satiety and appetite scores; *3)* intake of foods, energy, and macronutrients at lunch; and *4)* daily energy and macronutrients intake over the week. iAUCs were determined for the metabolic parameters and the VAS score profile by use of the trapezoidal method, counting also negative values for the postbreakfast period (0–120 min and 0–240 min). The effects of breakfast, time, and breakfast × time interaction for all variables were analyzed by repeated-measures ANOVA with the use of Greenhouse-Geisser or Huynh-Feldt corrections whether ε was lesser or greater than 0.75, respectively, when the assumption of sphericity was violated. Bonferroni post hoc tests were used for multiple comparisons. Spearman's correlation test was used to explore the relation between 0–120 iAUCs for satiety and appetite sensations and the perceived characteristics of breakfast [healthiness, satiety, palatability, and energy content, reported by Rosi et al. (26)]. The statistical analysis was performed with the Statistical Package for Social Sciences software (IBM SPSS Statistics, version 22.0; IBM Corp., Chicago, IL). A difference was considered significant at $P < 0.05$.

Results

Metabolic parameters related to food intake regulation. Serum insulin responses to breakfast were affected by breakfast, time, and breakfast × time interaction ($P < 0.001$ for all). Insulin concentrations peaked at 30 min after breakfast, returning towards baseline between 120 and 180 min (**Figure 2**A) after the consumption of BR-RICE, BR-BREAD, and BR-MUESLI. F-CTRL did not cause modifications in serum insulin concentrations. These differences among breakfasts were also evident when iAUC values were analyzed (Figure 2A). BR-RICE iAUC at 120 min was significantly higher compared with the other 3 breakfasts, whereas F-CTRL iAUC values were significantly lower than the other 3 treatments at both 120 and 240 min.

Plasma glucose concentrations were affected by breakfast, time, and breakfast × time interaction ($P < 0.001$ for all), and followed a similar trend to serum insulin, peaking at 30 min and returning towards baseline at 90 min post breakfast (Figure 2B). Plasma glucose concentrations were significantly higher after consumption of BR-RICE than for the other 2 test breakfasts (BR-BREAD or BR-MUESLI). Moreover, BR-RICE was the only test breakfast that resulted in a hypoglycemic rebound at 120 min. Plasma glucose concentrations did not change after F-CTRL consumption. Glucose iAUC at 120 min was significantly greater in BR-RICE than in BR-BREAD (Figure 2B), the 2 breakfasts with the highest and the lowest GI and GL, respectively.

Decreases in serum leptin concentrations after breakfast consumption were not different after the various breakfasts ($P > 0.05$) and constantly remained below baseline values (**Figure 3**A).

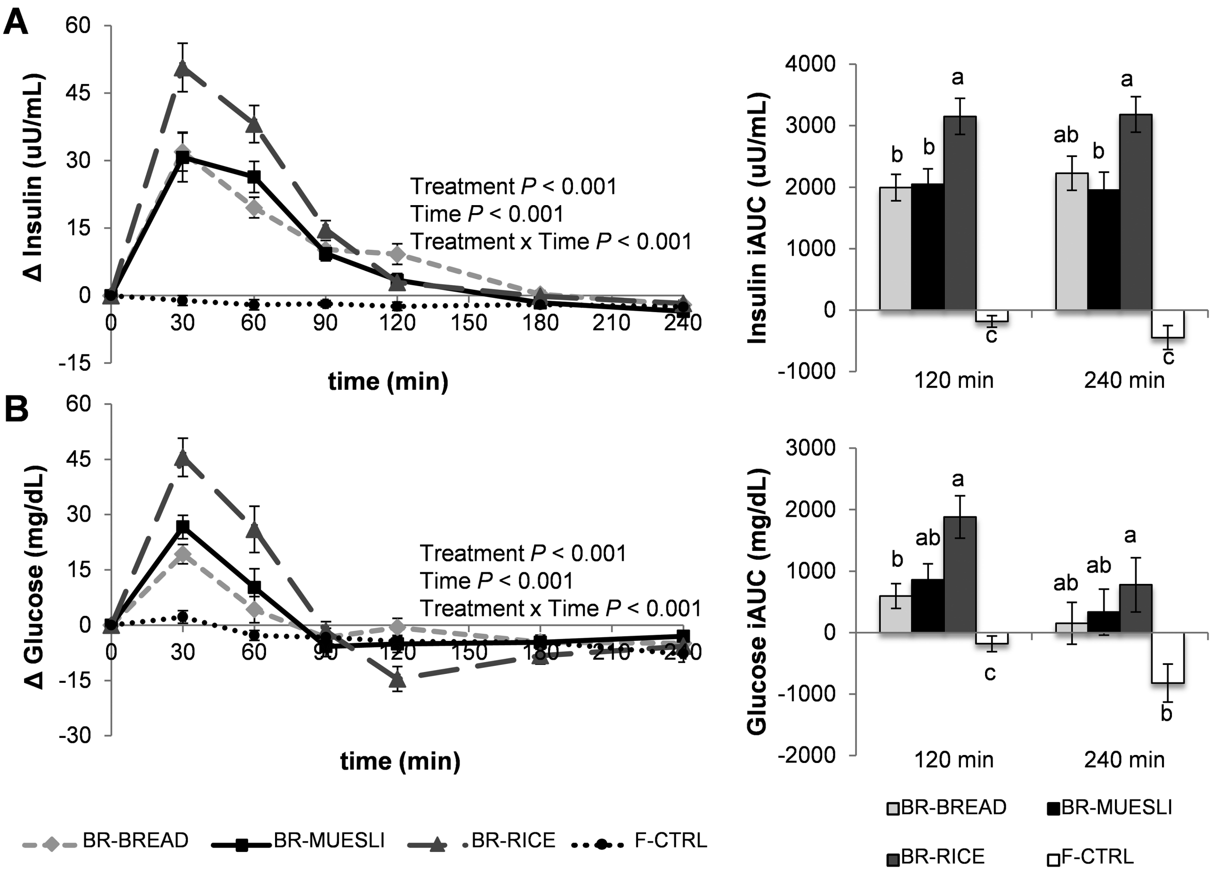

FIGURE 2 Postprandial incremental concentration and iAUCs for serum insulin (A) and plasma glucose (B) in healthy young men after intake of 3 iso-energetic experimental breakfasts and 1 energy-free control meal. Values are means ± SEMs, $n = 15$. Labeled values in the same grouped bars without a common letter differ, $P < 0.05$ (repeated-measures ANOVA with Bonferroni post hoc test). BR-BREAD, breakfast with bread with chocolate hazelnut spread, semi-skimmed milk, and an apple; BR-MUESLI, breakfast with muesli with dark chocolate chips and nuts, semi-skimmed milk, and an apple; BR-RICE, breakfast with chocolate-flavored puffed rice, semi-skimmed milk, and an apple; F-CTRL, fasting control treatment; iAUC, incremental area under the curve.

For plasma total ghrelin, interindividual variability was high, resulting in nonsignificant differences among the breakfasts ($P > 0.05$) (Figure 3B).

Postprandial plasma GLP-1 concentrations were not significantly affected by the type of breakfast ($P > 0.05$), although a main effect of time ($P < 0.05$) was noted. According to iAUC data for both the 0–120 min and 0–240 min periods, a significantly higher production of GLP-1 was found after consumption of BR-BREAD and BR-MUESLI compared with F-CTRL, whereas BR-RICE was not different from the other breakfasts (Figure 3C).

Time, type of breakfast, and breakfast × time interaction affected plasma NEFA responses ($P < 0.001$ for all). BR-BREAD, BR-MUESLI, and BR-RICE similarly decreased postprandial plasma NEFA concentrations, whereas F-CTRL was characterized by an increase in NEFA (Figure 3D). The significant reduction in plasma NEFA concentrations as a consequence of BR-BREAD, BR-MUESLI, and BR-RICE was also evident in terms of iAUC (Figure 3D).

Self-reported appetite and satiety ratings. The response curves for appetite and satiety ratings after breakfast consumption are shown in **Figure 4**. There were main effects of breakfast, time, and the interaction of breakfast × time for satiety ($P < 0.001$ for all) and appetite ratings ($P < 0.01$ for breakfast, and $P < 0.001$ for both time and breakfast × time). After F-CTRL, participants reported a higher appetite and a lower satiety response compared with the other breakfasts. When iAUCs were analyzed, statistically significant differences were registered for both appetite and satiety ratings between F-CTRL and the other 3 test breakfasts, but not among BR-BREAD, BR-MUESLI, and BR-RICE (Figure 4). Positive relations were observed between the satiety 0–120 min iAUCs and the perceived satiety ($\rho = 0.52$, $P < 0.001$), palatability ($\rho = 0.45$, $P < 0.001$), and energy-content ($\rho = 0.46$, $P < 0.001$) of the breakfast meals before consumption. On the contrary, appetite 0–120 min iAUCs were negatively associated with the perceived satiety ($\rho = -0.51$, $P < 0.001$), palatability ($\rho = -0.47$, $P < 0.001$), and energy-content ($\rho = -0.41$, $P < 0.001$). No significant relations were observed between the breakfast healthiness perception and either appetite or satiety 0–120 min iAUCs (**Supplemental Table 2**).

Ad libitum lunch. Food choices at lunch were not significantly influenced by the different breakfasts. Subjects consumed a similar amount of individual food items after the 4 breakfast conditions regardless of the type of breakfast, including the one mimicking fasting conditions (F-CTRL) (**Figure 5**A). Similarly, no differences among breakfasts were registered when single food items were grouped either for nutritional category (protein- compared with carbohydrate-based courses) or for healthiness perception (healthy compared with unhealthy) with the intent of evaluating the effect of group characteristics (Figure 5B, C). In agreement with these results, energy and

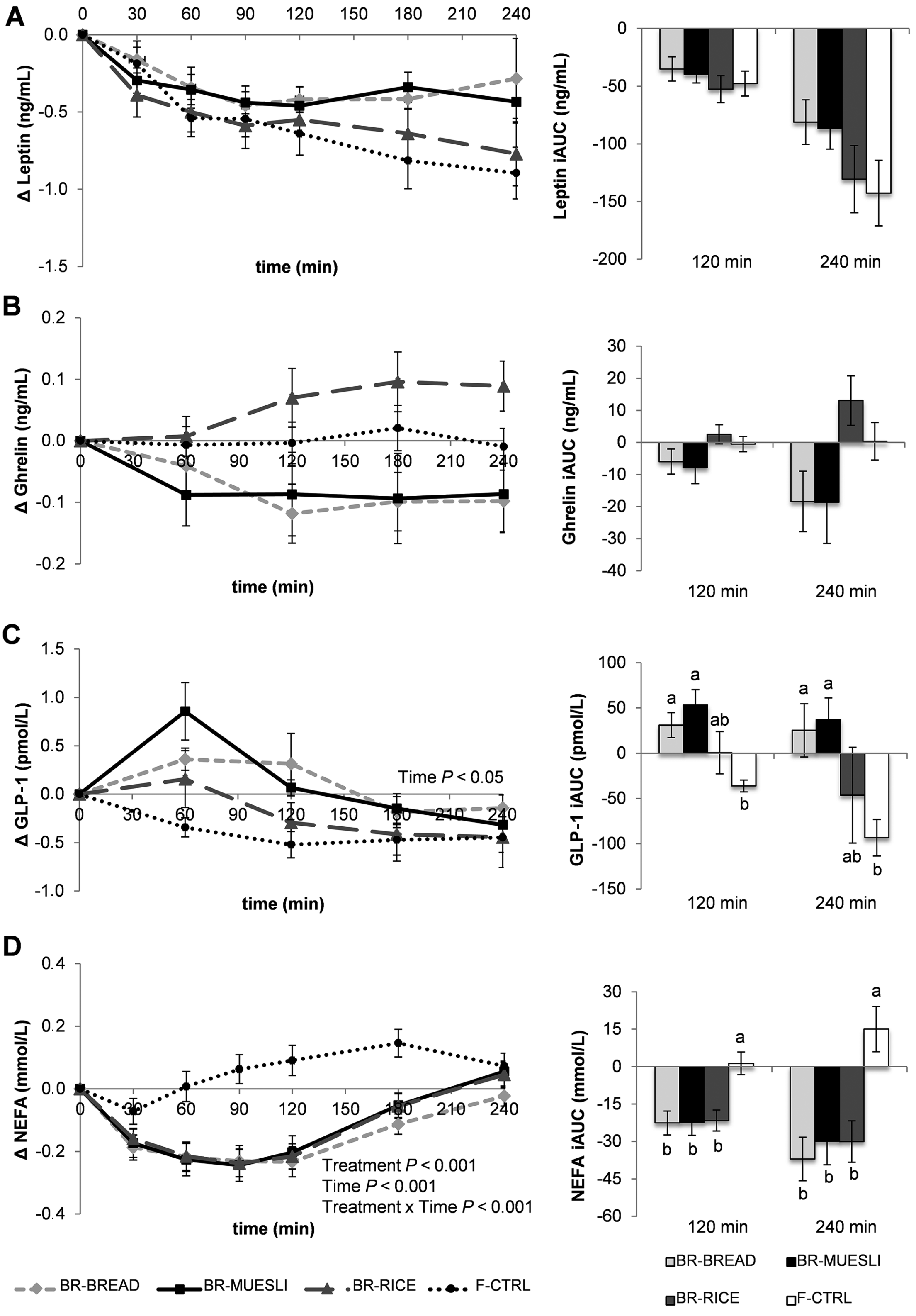

FIGURE 3 Postprandial incremental concentration and iAUCs for serum leptin (A), plasma ghrelin (B), plasma GLP-1 (C), and plasma NEFAs (D) in healthy young men after intake of 3 iso-energetic experimental breakfasts and 1 energy-free control meal. Values are means ± SEMs, $n = 15$. Labeled values in the same grouped bars without a common letter differ, $P < 0.05$ (repeated-measures ANOVA with Bonferroni post hoc test). BR-BREAD, breakfast with bread with chocolate hazelnut spread, semi-skimmed milk, and an apple; BR-MUESLI, breakfast with muesli with dark chocolate chips and nuts, semi-skimmed milk, and an apple; BR-RICE, breakfast with chocolate-flavored puffed rice, semi-skimmed milk, and an apple; F-CTRL, fasting control treatment; GLP-1, glucagon-like peptide-1; iAUC, incremental area under the curve; NEFA, nonesterified fatty acid.

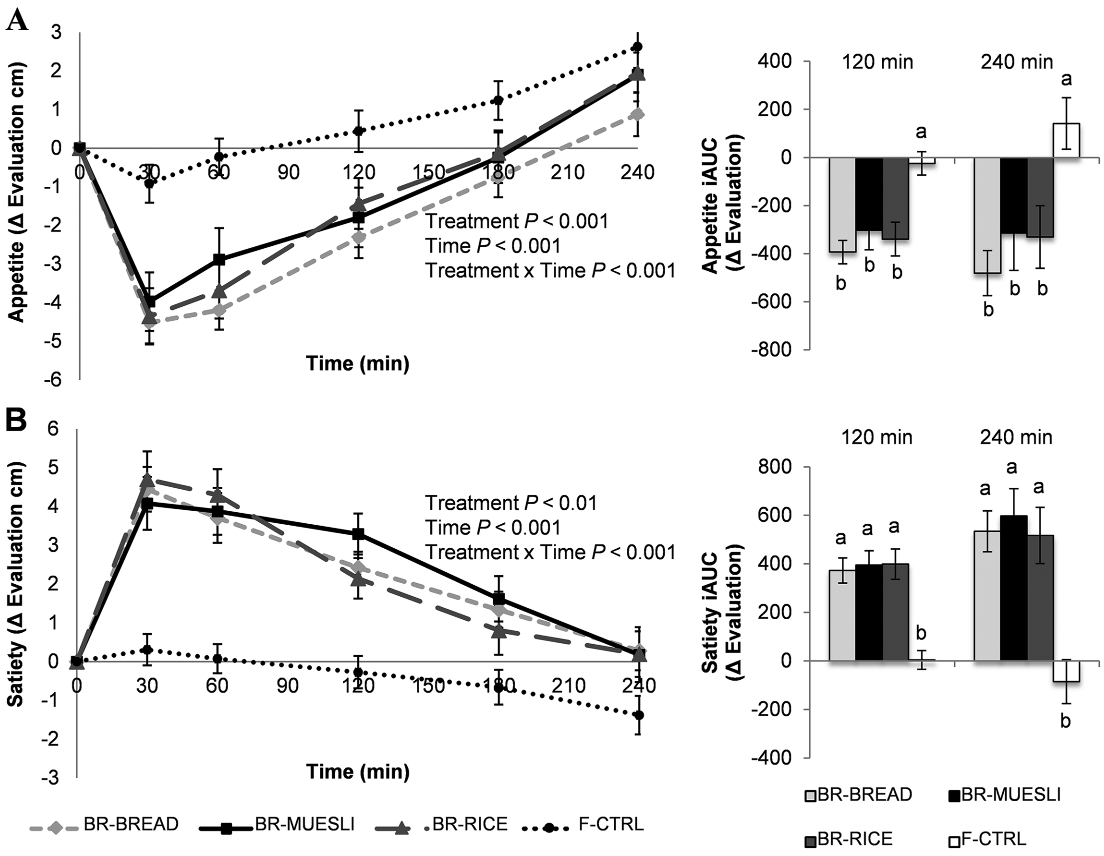

FIGURE 4 Postprandial appetite (A) and satiety (B) ratings over time (incremental curves and corresponding iAUCs) in healthy young men after intake of 3 iso-energetic experimental breakfasts and 1 energy-free control meal, as measured by VAS score answering to question A: "How hungry do you feel right now?" and to question B: "How full do you feel right now?" Values are means ± SEMs, $n = 15$. Labeled values in the same grouped bars without a common letter differ, $P < 0.05$ (repeated-measures ANOVA with Bonferroni post hoc test). BR-BREAD, breakfast with bread with chocolate hazelnut spread, semi-skimmed milk, and an apple; BR-MUESLI, breakfast with muesli with dark chocolate chips and nuts, semi-skimmed milk, and an apple; BR-RICE, breakfast with chocolate-flavored puffed rice, semi-skimmed milk, and an apple; F-CTRL, fasting control treatment; iAUC, incremental area under the curve; VAS, visual analog scale.

macronutrient intake at lunch did not significantly change after different breakfasts (**Table 2**).

Dietary intake throughout the week. Average daily energy intake did not vary among the different conditions ($P > 0.05$) and was around 2700–2800 kcal/d (Table 2). Considering that BR-BREAD, BR-MUESLI, and BR-RICE provided about 330 kcal/d whereas F-CTRL had virtually no caloric content, similar total daily energy intake was linked to an ~12% increase in energy intake for other-than-breakfast meal occasions during the F-CTRL condition. Indeed, when energy intake due to breakfast was not included, a significantly higher energy intake of about 300 kcal during the rest of the day was observed for F-CTRL compared with BR-MUESLI ($P = 0.023$) and BR-RICE ($P = 0.029$) (Table 2). Regarding macronutrients, daily intakes of proteins and fats were not affected by the type of breakfast (Table 2), although daily carbohydrate intake was lower for F-CTRL than for BR-BREAD ($P = 0.020$) and BR-RICE ($P = 0.025$) (Table 2). However, when macronutrient intake during the day was corrected excluding the nutrient value of breakfast, subjects consumed more proteins and fats as a result of morning fasting (F-CTRL) in comparison with BR-MUESLI ($P = 0.024$) and BR-RICE ($P = 0.021$), respectively (Table 2).

Discussion

This study investigated the metabolic effects of breakfasts differing in terms of nutritional and perceived characteristics and their effect on calories and macronutrient intake of foods consumed later in the day. Taking into account the perceived characteristics of the breakfasts, postprandial satiety profiles herein obtained matched well the perception of the satiating power of meals before eating. Regarding perceived palatability and energy content, contrasting results have been reported when using measures of subjective appetite sensations (32). In this work, a greater perceived palatability and energy content of breakfast was associated with higher-satiety and lower-hunger postprandial profiles.

As expected, breakfast consumption increased satiety and reduced appetite in the early postprandial phase, whereas ratings for the energy-free control breakfast fluctuated around baseline. However, no differences in satiety and appetite among the 3 iso-energetic breakfasts were detected, contrary to the expectations that specific breakfast characteristics (e.g., ingredients, physical form, GI, and GL) could influence these parameters in a specific way. These results on postprandial satiety are in agreement with another study evaluating similar foods, in which satiety and desire to eat sensations were reported to be similar after having 7 iso-energetic cereal-based breakfasts (33).

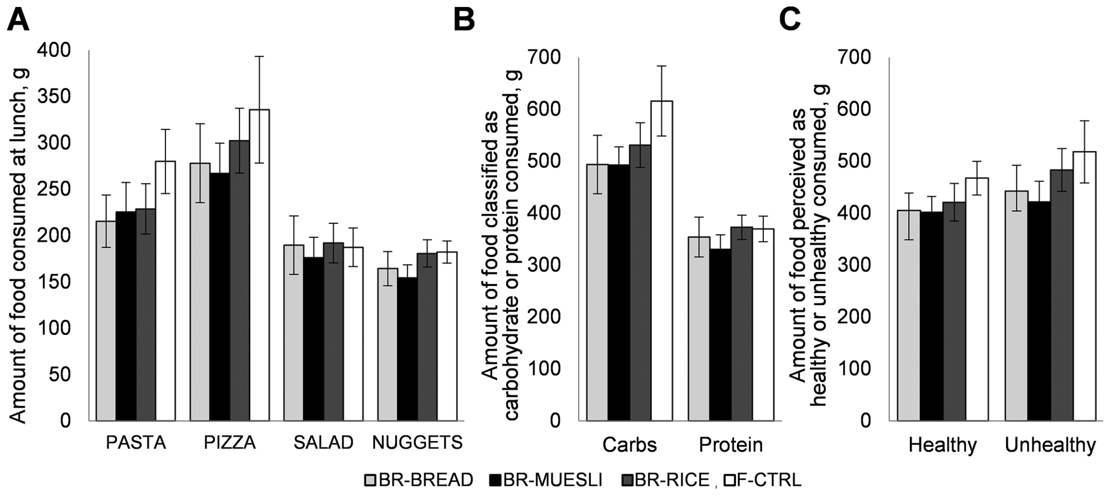

FIGURE 5 Amount (grams) of food consumed during the ad libitum lunch for each single dish (A), nutritional category (B), and healthiness perception (C) by healthy young men after intake of 3 iso-energetic experimental breakfasts and 1 energy-free control meal. Values are means ± SEMs, *n* = 15. BR-BREAD, breakfast with bread with chocolate hazelnut spread, semi-skimmed milk, and an apple; BR-MUESLI, breakfast with muesli with dark chocolate chips and nuts, semi-skimmed milk, and an apple; BR-RICE, breakfast with chocolate-flavored puffed rice, semi-skimmed milk, and an apple; Carbs, carbohydrate-based (pasta with vegetables, or pizza with French fries); F-CTRL, fasting control treatment; Healthy, food perceived as healthy (pasta with vegetables, or salad with ham and cheese); Protein, protein-based (salad with ham and cheese, or chicken nuggets); Unhealthy, food perceived as less healthy (pizza with French fries, or chicken nuggets).

In terms of objective attributes of breakfasts and their relation with self-reported appetite and satiety ratings, differences among the experimental breakfasts were expected. The physical form of foodstuffs generally affects satiety, with more solid food usually resulting in greater satiety (34). Similarly, carbohydrates in liquid food have been reported to produce lower satiety than carbohydrates provided in solid form (35). Cereals included in BR-MUESLI and BR-RICE presented a semi-solid consistency, requiring consumption with a spoon, and thus it was hypothesized that they might elicit a lower-satiety postprandial profile than the bread with spread contained in BR-BREAD, which was a solid food. However, differences among treatments due to the consistency of the breakfast items were not revealed. A likely explanation can be found in the different composition of our breakfast meals with respect to those reported by Samra and Anderson (34), because solid foods were not present at all in their study whereas apples were included in our breakfast treatments. Moreover, differences in the consistency could have been lessened by the different volume of the breakfast meals, because the semi-solid breakfasts had a higher volume than the BR-BREAD.

With regard to macronutrients, it has been reported that protein-based breakfasts have a greater effect on satiety than carbohydrate-based ones, but also that the carbohydrate quality of breakfasts could differently influence satiety (36, 37). In previous investigations, the consumption of low-GI breakfasts resulted in a higher control of hunger and a lower subsequent food intake with respect to high-GI breakfasts (17, 38). In our case, considering GI, no differences were observed in terms of modulation of postprandial appetite and satiety ratings, and this could be attributed to the relatively small difference in breakfast GIs. On the contrary, the difference of carbohydrate quality was enough to significantly influence markers of glucose metabolism, in agreement with previous findings in normal-weight subjects (34, 39). The GL of breakfast affected glucose and insulin peak concentrations that were significantly lower for BR-BREAD and BR-MUESLI compared with BR-RICE and fully consistent with the GI and GL ranking of mixed meals calculated for breakfasts on the basis of the ingredients' GI and GL. This underlines the validity of GI and GL as food characteristics able to affect postprandial glycemic and insulinemic response. Therefore, considering the potential role of glycemic control in the prevention of chronic diseases (40–44), the consumption of foods with lower GI and GL at breakfast might be encouraged.

Concerning food intake, differences in GI of our breakfasts did not significantly affect food intake at lunch after direct assessment of ad libitum intake. Actually, no significant differences were observed between the 4 breakfasts, including the calorie-free one, at the subsequent ad libitum lunch for either food quantity or macronutrient intake. Similar results were registered by Chowdhury et al. (45) who did not observe compensatory intake during an ad libitum lunch after extended morning fasting in obese adults, whereas lean individuals had significantly higher energy intake during an ad libitum lunch when they were fasting than when they had a carbohydrate-rich breakfast in an acute crossover test (8). However, over a longer period, ad libitum energy intake at lunch was not affected by extended morning fasting or having a daily breakfast for 6 wk (46). In spite of different metabolic profiles and appetite and satiety ratings in the early postprandial phase, it should be noted that values tended to return to baseline levels 4 h after breakfast. In fact, subjects reported almost the same satiety and returned to baseline blood values independently from the type of breakfast before consuming the ad libitum lunch. In this context, previous studies showed that the impact of a test meal in reducing subsequent energy intake is decreased as the period between 2 meals increases, suggesting that periods of time between breakfast and lunch >4 h may limit the effects of breakfast on satiety (5, 37). With respect to the food choices, volunteers showed a preference for carbohydrate-rich foods (i.e., pizza and pasta) independently of the type of breakfast eaten. No differences were observed between choices for healthy or unhealthy foods, suggesting that the healthiness perception of breakfast did not influence a compensatory choice of healthy/unhealthy foodstuffs at lunch. It is worth mentioning that energy intake at lunch was very high compared with normal

TABLE 2 Mean energy and macronutrient intakes during ad libitum lunch, and for total day and rest of the day corrected for breakfast intakes over 1 wk, after consumption of 3 iso-energetic experimental breakfasts and 1 energy-free control meal by healthy young men[1]

Intakes	BR-BREAD	BR-MUESLI	BR-RICE	F-CTRL
Ad libitum lunch				
Energy, kcal	1762 ± 149	1705 ± 85	1879 ± 113	2043 ± 156
Protein, g	76.3 ± 6.7	73.1 ± 3.8	81.1 ± 4.6	85.8 ± 5.9
(% energy)	17	17	17	17
Fat, g	78.2 ± 6.7	74.0 ± 4.1	82.5 ± 4.7	87.0 ± 6.3
(% energy)	40	39	40	38
Carbohydrate, g	178 ± 17.5	177 ± 11.3	192 ± 13.6	217 ± 19.8
(% energy)	40	41	41	43
Total day				
Energy, kcal	2806 ± 130	2707 ± 156	2706 ± 157	2712 ± 199
Protein, g	107 ± 5.0	99.3 ± 5.3	101 ± 5.0	104 ± 6.6
(% energy)	15	15	15	15
Fat, g	115 ± 5.5	114 ± 8.1	105 ± 6.9	121 ± 10.2
(% energy)	37	38	35	40
Carbohydrate, g	322 ± 19.5^{a}	300 ± 18.4^{ab}	324 ± 20.2^{a}	280 ± 20.9^{b}
(% energy)	46	44	48	41
Rest of the day[2]				
Energy, kcal	2473 ± 130^{ab}	2379 ± 156^{b}	2376 ± 157^{b}	2712 ± 199^{a}
Protein, g	97.2 ± 5.0^{ab}	90.0 ± 5.3^{b}	92.6 ± 5.0^{ab}	104 ± 6.6^{a}
(% energy)	16	15	16	15
Fat, g	103 ± 19.5^{ab}	103 ± 18.4^{ab}	101 ± 20.2^{b}	121 ± 20.9^{a}
(% energy)	38	39	38	40
Carbohydrate, g	273 ± 5.5	252 ± 8.1	258 ± 6.9	280 ± 10.2
(% energy)	44	42	43	41

[1] Values are means ± SEMs, $n = 15$ and percentages of macronutrient contributions to total daily energy intake. Labeled means in a row without a common superscript letter differ, $P < 0.05$ (repeated-measures ANOVA with Bonferroni post hoc test). BR-BREAD, breakfast with bread with chocolate hazelnut spread, semi-skimmed milk, and an apple; BR-MUESLI, breakfast with muesli with dark chocolate chips and nuts, semi-skimmed milk, and an apple; BR-RICE, breakfast with chocolate-flavored puffed rice, semi-skimmed milk, and an apple; F-CTRL, fasting control treatment.

[2] Rest of the day values were calculated as total day intakes minus breakfast intakes over 1 wk.

habits (it was up to two-thirds of the average daily energy requirements), confirming that ad libitum feeding is generally associated with excessive food intake, as previously reported by other authors (37, 47). However, food and macronutrient intakes registered over 1 wk in free-living conditions suggest a potential long-term compensation during the day for prolonged omission of energy intake through breakfast skipping. It has been proposed that omitting breakfast can lead to a redistribution of the daily energy intake, because of an inverse association between the energy content of breakfast and the energy intake later in the day (9). However, a recent review of the literature identified breakfast skipping as an effective strategy to reduce total energy intake (48). In our experiment, total daily energy was not different between breakfasts, suggesting that calories not consumed at breakfast in the F-CTRL condition may be evenly balanced during the remaining part of the day over 1 wk. In addition, considering anthropometric characteristics and lifestyle of volunteers, the mean energy intake (2700–2800 kcal/d) was compliant and not in excess according to national recommendations (49), with no differences between the types of breakfast. In addition, no differences between the 4 conditions were found for macronutrient contributions to total daily energy intake, which were found to be about 41–48%, 35–40%, and 15% for carbohydrates, lipids, and proteins, respectively. Nevertheless, F-CTRL was associated with the lowest and the highest values respectively for carbohydrates and lipids, showing a lower nutritional profile. Irrespective of the condition, fat's contribution to the daily energy intake was slightly higher than the recommended 20–35%, whereas carbohydrate's contribution fell borderline within the recommended values of 45–60% (49, 50). The lowest intake of energy from carbohydrate and the highest intake of energy from lipids were observed after the energy-free breakfast meal, probably due to the fact that missing consumption of carbohydrates at breakfast was not compensated for during the rest of the day.

It must be noted that the present study was performed on a small and homogeneous group of healthy men. This can represent a possible limitation of the work, and future studies with larger and more heterogeneous subjects (i.e., both sexes, overweight and obese, different age) are needed to better generalize the effects of breakfast consumption. Another limit is that volunteers, belonging to a healthy general population, possibly were not particularly health-conscious. Therefore, the perception of the nutritional quality of breakfast might not be representative of the influence that cognitive decisions regarding food choices may have for more health-conscious subjects. Moreover, assessment of satiety perception and of metabolic parameters after the ad libitum lunch could be of interest and should be integrated in future trials. Lastly, the exact measure of the daily physical activity performed by participants should be considered in further studies allowing researchers to investigate the effect of breakfast upon energy balance.

In summary, our findings suggest that the consumption of breakfast positively affects postprandial satiety if compared with an energy-free breakfast, but slight nutritional or perceived characteristics of breakfasts are of little importance in determining significant shifts in energy intake or in the characteristics of food consumed later on. However, even single items of otherwise nutritionally balanced breakfasts could affect metabolic and endocrine responses, with breakfasts composed of an apple and a glass of semi-skimmed milk integrated with low-GI foods, such as white bread with chocolate hazelnut spread or muesli with chocolate and nuts, resulting in better postprandial metabolic profiles than higher-GI/GL foods.

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