The Journal of Nutrition
Nutritional Epidemiology

Nutrient-Dense Food Groups Have High Energy Costs: An Econometric Approach to Nutrient Profiling[1,2]

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Abstract

Consumers wishing to replace some of the foods in their diets with more nutrient-dense options need to be able to identify such foods on the basis of nutrient profiling. The present study used nutrient profiling to rank 7 major food groups and 25 subgroups in terms of their contribution to dietary energy, diet quality, and diet cost for 1332 adult participants in the French National INCA1 Study. Nutrient profiles were based on the presence of 23 qualifying nutrients, expressed as the percentage of nutrient adequacy per 8 MJ, and 3 negative or disqualifying nutrients, expressed as the percentage of the maximal recommended values for saturated fatty acids, added sugar, and sodium per 1.4 kg. Calculated cost of energy (€/8 MJ) was based on the mean retail price of 619 foods in the nutrient composition database. The meat and the fruit and vegetables food groups had the highest nutritional quality but were associated with highest energy costs. Sweets and salted snacks had the lowest nutritional quality but were also one of the least expensive sources of dietary energy. Starches and grains were unique because they were low in disqualifying nutrients yet provided low-cost dietary energy. Within each major food group, some subgroups had a higher nutritient-to-price ratio than others. However, the fact that food groups with the more favorable nutrient profiles were also associated with higher energy costs suggests that the present structure of food prices may be a barrier to the adoption of food-based dietary guidelines, at least by low-income households. J. Nutr. 137: 1815–1820, 2007.

Introduction

Food prices and diet costs may be one factor limiting the adoption of healthier diets, especially by the low-income consumer. That food prices affect food purchases and food consumption has been repeatedly shown by studies in economics (1,2), marketing (3), consumer behavior (4,5), and nutritional epidemiology (6).

If nutrient-poor diets cost less, then economic factors could help explain the high prevalence of nutrient deficiencies and nutrition-related diseases, particularly obesity, among the more disadvantaged populations (7–9). If healthier diets cost more, then economic barriers may help explain the low consumption of fruits, vegetables (10,11), and fish (12) among the lower-income groups. Diet modeling studies using linear programming suggest that food budget constraints preferentially orient food choices toward energy-dense diets that are low in essential nutrients (13,14). In addition, there is accumulating evidence that the recommended healthier, balanced, or more prudent diets are associated with higher costs than are the "unhealthy" diets (15–17). In particular, the consumption of higher amounts of fruit and vegetables (18) and essential micronutrients (19) has been associated with higher diet costs, adjusted for energy. Conversely, high dietary energy density (amount of energy in 100 g of food) has been associated with lower diet costs (20).

A science-based nutrient profiling system, based on the nutritional characteristics of individual foods or food groups, is currently under consideration by the European Commission (21). Intended for consumer protection, the system will determine which foods or categories of foods will be allowed or disqualified from certain nutritional or health claims (21). Although diverse nutrient profiling schemes are available (22,23), few have considered the issue of food costs and nutrient-to-price ratios. The present study tested the hypothesis that the inverse relationship between nutrient density and energy cost holds not only between but also within food groups. In both cases, the more nutrient-dense foods and food categories would be associated

[1] Supported by the French National Research Agency's 2005–2008 Nutritional Policies project, the French National Institute for Health Prevention and Education (INPES), and by the USDA Cooperative State Research, Education, and Extension Service (CSREES), grant 2004-35215-14441.
[2] Author disclosures: M. Maillot, N. Darmon, M. Darmon, L. Lafay, and A. Drewnowski, no conflicts of interest.
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Manuscript received 13 December 2006. Initial review completed 31 January 2007. Revision accepted 11 May 2007.

with higher costs, whereas the least nutrient-dense foods and categories would be associated with lower costs. The relationship between the qualifying (beneficial) and the disqualifying (negative) nutrients and energy cost was a topic of particular interest to us. We used an across-the-board nutrient profiling system to estimate the nutritional quality of food groups, based on 23 qualifying nutrients and 3 disqualifying nutrients, saturated fatty acids (SFA),[9] added sugars, and sodium. Nutrient profiling of foods has been recently described as a powerful tool to rank foodstuffs according to their contribution to a balanced diet (22).

Materials and Methods

Food consumption data. The national INCA dietary survey, conducted in 1999 by the French National Agency for Food Safety, provided the food consumption data used in this study. This survey was based on a nationally representative sample of 1985 French adults, aged 15–92 y, who were selected using the quota method of sampling (24). All participants completed a 7-d food record, which was aided by a photographic manual of portion sizes. Subjects who under- or over-reported their energy intakes (284 men and 312 women) according to the method of Black (25) were removed from the sample. The physical activity level assumed in the calculation of the threshold was 1.55, corresponding to seated work with low walking and leisure activity. The final sample of 1332 included 596 men (age range of 15 to 92 y) and 736 women (age range of 15 to 90 y).

Drinking water, diet beverages, tea, and coffee were excluded from all analyses. The nutritional composition of the remaining 619 foods was computed from the INCA food composition database (26), the Suvimax food composition database (27), and other databases (28–30) including the USDA food composition data for zinc, copper, iodine, and selenium (31). The French mean national 1997 retail prices, mainly obtained from marketing research (SECODIP), were also added to the analysis. All prices were adjusted for preparation and waste using conversion factors.

Food groups. The foods were aggregated into 7 major food groups and 25 food subgroups (**Table 1**) according to the classification system used to develop the French food-based dietary guidelines (32). The starches and grains group included grains, starchy vegetables, dry beans, and peas. The fruit subgroup included fruit juice and other processed fruits; the vegetables subgroup included frozen and canned vegetables as well as soups. The sweets subgroup included sweets, chocolate, pastries, cookies, ice-creams, and desserts; the salted subgroup included chips, savory snacks, and salted nuts. The mixed dishes subgroup included foods like couscous-based dishes, paella, and cassoulet (french equivalent of a bean dish with meat); and a snacks subgroup included foods like pizzas, quiches, and sandwiches.

Contribution of food groups to diet energy and diet cost. Daily energy intakes (in MJ/d) and daily diet costs (in €/d) were calculated for each participant. The percentage of contributions of each food group to total energy intakes and to the estimated diet costs were determined. The cost of energy was calculated separately for each food group and subgroup and was expressed in €/8 MJ (i.e., €/1913 kcal). We chose the 8 MJ value because it is close to the recommended energy intakes for the studied population of French adults: 9.2 MJ (2200 kcal) for inactive men and 7.5 MJ (1800 kcal) for inactive women.

Nutrient profiling of food groups. Nutrient profiling of the 7 food groups and 25 subgroups was based on 2 indicators. An expanded and modified version of a previously used nutrient density score (NDS) (33) assessed the presence of qualifying nutrients thought to have a beneficial effect on health. The score, based on 23 nutrients (**Table 2**), was the mean of percentages of the French 2001 recommended dietary allowances (RDA) (34) for each nutrient based on 8 MJ (1913 kcal) of the food group consumed. The NDS algorithm was as follows:

$$NDS_{ik} = [(\sum_{P=1}^{P=23}(Nutrient_{ikp}/RDA_p)/23) \times 100] \times 8/EI_{ik}$$

where $Nutrient_{ikp}$ is the daily content (g, mg, or μg) of nutrient p provided by group (or subgroup) k to a subject i, and RDA_p is the French RDA for nutrient p. EI_{ik} is the energy content (in MJ) provided by group k to a subject i. A NDS of 100% indicates that the consumption of 8 MJ (i.e., 1913 kcal) of any one food group or subgroup covers a mean of 100% of the RDA for 23 nutrients (34) (Table 2). Only those nutrients naturally present in foods were included in the calculation of the NDS.

We developed a second indicator of limited nutrients (LIM) specifically for this study. The LIM used 3 negative or disqualifying nutrients,

[9] Abbreviations used: LIM, limited nutrient score; MRV, maximal recommended value; NDS, nutrient density score; RDA, recommended dietary allowances; SFA, saturated fatty acids.

TABLE 1 Food groups, subgroups and number of foods per group

Groups	*n*	Subgroups
Meat	166	Shellfish, fatty fish, lean fish, poultry, red meat, organ meats, deli meats, eggs
Fruit and vegetables	114	Vegetables, fruit, dried fruit, nuts
Mixed dishes and snacks	70	Mixed dishes, snacks
Dairy	87	Yogurts, cheese, milk
Starches and grains	37	Legumes, whole grains, refined grains, potatoes
Sweets and salted snacks	107	Sweets, salted snacks
Added fats	39	Animal fats, vegetable fats

TABLE 2 Recommended dietary allowances and maximal recommended values used to calculate the nutrient density and the limited nutrient scores

	Men	Women
Nutrients	RDA	RDA
Proteins, *g/d*	70	50
Fiber, *g/d*	30	30
Linoleic acid, *g/d*	10	8
Linolenic acid, *g/d*	2	1.6
Docosahexaenoic, *g/d*	0.12	0,10
Vitamin A, *µg/d*	800	600
Thiamin, *mg/d*	1.3	1.1
Riboflavin, *mg/d*	1.6	1.5
Niacin, *mg/d*	14	11
Vitamin B-6, *mg/d*	1.8	1.5
Folates, *µg/d*	330	300
Vitamin B-12, *µg/d*	2.4	2.4
Ascorbic acid, *mg/d*	110	110
Vitamin E, *mg/d*	12	12
Vitamin D, *µg/d*	5	5
Calcium, *mg/d*	900	900
Potassium, *mg/d*	3100	3100
Iron, *mg/d*	9	16
Magnesium, *mg/d*	420	360
Zinc, *mg/d*	12	10
Copper, *mg/d*	2.0	1.5
Iodine, *mg/d*	150	150
Selenium, *µg/d*	60	50
Limited nutrients	MRV	MRV
Saturated fat acids, *g/d*	25	20
Added sugars, g/d	55	45
Sodium, *mg/d*	2365	2365

which, when present in a food, could disqualify it from bearing a nutritional or health claim. Unlike the NDS, the LIM was calculated for a given quantity, not a given energy content, to avoid favoring energy-dense foods. We chose a quantity of 1.4 kg, which approximated the daily intake of foods (excluding alcohol and nonenergetic beverages) in this population of French adults (1523 g for men and 1302 g for women).

The LIM was calculated as follows:

$$\mathrm{LIM}_{ik} = [(\sum_{t=1}^{t=3}(L_{ikt}/\mathrm{MRV}_t)/3) \times 100] \times 1400/Q_{ik},$$

where L_{ikt} is the daily amount (in g or mg) of LIM t provided by group (or subgroup) k to a subject i. MRV_t is the maximal recommended value for limited nutrient t (34). Q_{ik} is the quantity of foods (in g) from group k consumed by subject i. The 3 limited nutrients were sodium, simple added sugars, and SFA. The MRV for SFA and added sugars corresponded to 10% of the recommended energy intake, i.e., 9.2 MJ (2200 kcal) for inactive men and 7.5 MJ (1800 kcal) for inactive women (35). The MRV for sodium corresponds to a daily intake of 6 g NaCl.

A LIM of 100% would indicate that the consumption of 1.4 kg of any one food group or subgroup would provide a mean of 100% of the MRV for sodium, added sugars, and SFA.

Statistical analyses. Differences between means were tested using ANOVA. Food groups were sorted by decreasing cost of energy, and decreasing and increasing trends of mean NDS and LIM were respectively tested. All models were adjusted for within-subject effect. Statistical significance was determined at $\alpha = 0.05$. All analyses were performed using SAS software, version 9.1 (SAS Institute).

Results

Mean energy intakes were 9.9 MJ/d (2368 kcal/d) for men and 7.8 MJ/d (1866 kcal/d) for women. The daily cost of the participants' diets was estimated at 5.26 €/d (i.e., $6.89/d) for men and 4.26 €/d (i.e., $5.59/d) for women. The mean cost of the standard daily energy ration of 8 MJ was therefore 4.25 € (i.e., $2.90/1000 kcal) for men and 4.37 € (i.e., $2.28/1000 kcal) for women.

Contribution of food groups to diet energy and diet cost. We calculated the contribution of each of the 7 major food groups to the total energy content and total cost of diets consumed by the INCA participants as well as the cost of dietary energy (in €/8 MJ) for each food group (**Fig. 1***A*). Food groups that contributed the most energy to the population diet were not those that contributed the most to diet cost. In this population sample, fruit and vegetables contributed only 8% of the total dietary energy, but accounted for 17% of total diet cost. The meat group contributed 18% of total energy intakes but 35% of diet costs, whereas mixed dishes and snacks contributed 10% energy and 13% of diet cost. Conversely, starches and grains, sweets and salty snacks, and added fats contributed much more dietary energy in relation to cost. Starches and grains accounted for 23% of dietary energy but only 9% of the daily diet cost, whereas added fats provided 10% of dietary energy and 2% of diet cost. Dairy products were well balanced with respect to dietary energy and diet cost, contributing ~11% to each. This energy-to-cost relation by food group was illustrated by ranking the food groups according to their decreasing order of energy cost (Fig. 1*A*).

Nutrient profiling and cost of energy of food groups. The relationship between mean NDS and cost of energy for each of the 7 major food groups is indicated in Figure 1*B*. The fruit and vegetables group had the highest mean NDS, covering 210% of the RDA. For the same quantity of energy (8 MJ), the meat group

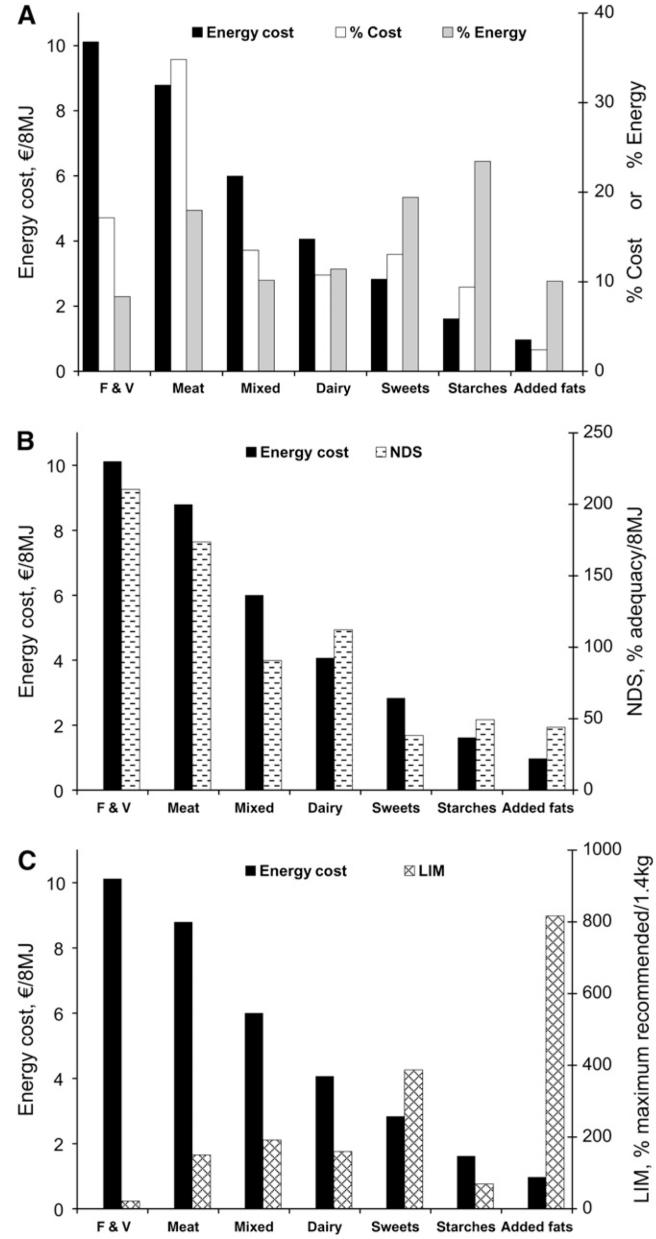

FIGURE 1 Energy and cost contributions (%) to the total energy content and total cost of diets (*A*), NDS (*B*), LIM (*C*), and dietary energy cost (*A, B, C*) of each of the 7 food groups consumed by INCA participants. P for decreasing and increasing trend of NDS <0.01 and of LIM <0.01, respectively.

covered a mean of 174% of the RDA, whereas the milk group covered 112%. The remaining food groups all had NDS below 100%, with sweets and salted snacks scoring the lowest (38%).

The relationship between mean limited nutrient score and cost of energy among the 7 major food groups is shown in Figure 1*C*. The fruit and vegetables group had the lowest mean LIM, with 1.4 kg providing only 21% of MRV. For the same quantity, the starches and grains group covered a mean of 76%. The remaining food groups all had LIM >100%, with added fats and sweets and salted snacks scoring the highest (816% and 387%, respectively).

The lower energy cost was paralleled by a lower NDS (*P* for trend = 0.01) and by a higher LIM (*P* for trend = 0.01) (Fig. 1*B*, *C*). These data confirm the hypothesis that higher energy costs were associated with higher nutritional quality, whereas lower energy costs were associated with lower nutritional quality. The mixed dishes, snacks, and dairy products, which had intermediate costs of energy, were also intermediate in terms of nutritional quality: they had relatively high NDS (close to 100%) as well as high LIM (>150%). However, this nutritional quality-to-price hierarchy among food groups was not absolute. Starches and grains were unique because they provided dietary energy at a low cost (2.0 €/8 MJ or $1.37/1000 kcal), without containing important amounts of disqualifying nutrients. Dairy products had a better nutritional quality (both a higher NDS and a lower LIM) than mixed dishes and snacks, although they were less expensive sources of energy. Sweets and salted snacks were relatively expensive sources of energy (3.5 €/8 MJ or $2.40/1000 kcal), given their low NDS (38%) and their high LIM (387%).

Nutrient profiling and cost of energy for food subgroups. The NDS and LIM for each of the 25 food subgroups were ranked according to decreasing cost of energy within each food group (**Table 3**). Among the meat group, organ meats had the highest NDS (754%) and were associated with a low cost of energy. In contrast, fish and shellfish had NDS that were almost as high but were also the most expensive in terms of energy cost. Deli meats had the lowest NDS (120%) and the highest LIM (454%) in the meat group. Eggs had a good nutritional quality-to-price ratio insofar as they had the lowest energy cost in this group for intermediate values of both NDS and LIM.

Vegetables and fruit had NDS >100% and LIM <100%. Dried fruits were less expensive as source of energy than fruit and vegetables, but their nutrient densities were also lower. Nuts were the least expensive source of energy in this group, but they also had the highest LIM.

In the dairy group, milk had higher nutritional quality-to-price ratio than either cheese or yogurt, in that it was the least expensive source of energy and had both the highest NDS and the lowest LIM. In the starches and grains group, all subgroups had low LIM. Legumes also had high NDS (156%). The nutritional quality of sweets and salted snacks was low (low NDS and high LIM). Within the added fats group, vegetable fats had a higher nutritional quality-to-price ratio than animal fats: they had both higher NDS and lower LIM for a lower cost of energy.

TABLE 3 Nutrient density score, limited nutrient score, and cost of energy of food subgroups consumed by INCA participants[1]

Groups and subgroups	n^2	NDS *%/8 MJ*	LIM *%/1.4 kg*	Cost of energy *€/8 MJ*
Meat				
Shellfish	370	643 ± 373	64 ± 28	33.2 ± 20.4
Lean fish	921	375 ± 92	60 ± 32	15.8 ± 8.8
Fatty fish	454	622 ± 188	130 ± 100	14.4 ± 8.1
Red meat	1297	147 ± 30	138 ± 42	10.3 ± 3.1
Poultry	1051	168 ± 62	63 ± 30	8.8 ± 2.6
Organ meats	262	754 ± 551	83 ± 42	7.4 ± 3.4
Deli meats	1102	120 ± 75	454 ± 103	4.8 ± 2.0
Eggs	889	212 ± 20	139 ± 32	3.2 ± 0.3
Fruit and vegetables				
Vegetables	1318	352 ± 172	27 ± 14	15.1 ± 8.1
Fruit	1220	134 ± 50	13 ± 22	7.7 ± 3.2
Dried fruit	63	85 ± 32	4.7 ± 1.9	3.9 ± 0.9
Nuts	173	120 ± 23	145 ± 40	1.7 ± 0.9
Mixed dishes and snacks				
Mixed dishes	967	106 ± 40	155 ± 50	6.7 ± 4.6
Snacks	1027	80 ± 18	229 ± 77	5.4 ± 2.6
Dairy				
Yogurts	1040	119 ± 31	65 ± 43	4.7 ± 1.0
Cheese	1238	101 ± 15	478 ± 66	4.7 ± 1.4
Milk	913	138 ± 8.7	29 ± 5.9	2.1 ± 0.2
Starches and grains				
Legumes	405	156 ± 24	24 ± 23	3.6 ± 0.9
Whole grains	146	83 ± 10	98 ± 24	3.5 ± 0.9
Potatoes	1243	75 ± 12	58 ± 38	1.6 ± 0.6
Refined grains	1326	40 ± 2.8	77 ± 21	1.5 ± 0.3
Sweets and salted snacks				
Salted snacks	493	80 ± 99	422 ± 150	6.2 ± 14
Sweets	1326	37 ± 15	388 ± 167	2.8 ± 1.1
Added fats				
Animal fats	1330	25 ± 2.9	1040 ± 185	1.2 ± 0.1
Vegetable fats	1325	80 ± 13	360 ± 52	0.6 ± 0.1

[1] Values are means ± SD.
[2] For each subgroup, *n* indicates the number of participants consuming foods from this subgroup.

Discussion

The data show that food groups and subgroups differ widely in terms of nutritional quality and in terms of cost per MJ. The meat and the fruit and vegetables groups that offered the highest NDS overall were also the most expensive in terms of cost per MJ. Conversely, added fats provided dietary energy at a very low cost and had both a low NDS and a high content of negative or disqualifying nutrients. Mixed dishes, snacks, and dairy products were intermediate in rank, both in terms of nutritional quality and in terms of cost of energy. Sweets and salted snacks had a lower nutritional quality than would be expected from their relatively high cost of energy.

Both fish and vegetables and fruit had good nutrient profiles, as indicated by very high NDS and by low LIM. However, they were also associated with higher costs per MJ and therefore with higher diet costs. On the other hand, as our previous studies showed (33), vegetables and fruit provided an affordable package of nutrients (as opposed to energy) per unit cost.

Overall, starches and grains had very favorable nutritional quality-to-price ratio. These foods appear to be a good choice, particularly whole or unrefined staples, which provide adequate nutrition at a moderate cost. Whole-grain cereals generally provided twice the amount of nutrients than refined cereal products, but at twice the price. It will be interesting to determine whether the food choices made by lower income and food insecure persons, high in grains and starches and low in vegetables and fruit (7), is a rational behavior in response to economic constraints, or whether tradition and education are mainly involved in these choices.

Although a clear ranking of nutrient-to-price ratios was found among food groups, food subgroups showed more diversity. Although several food subgroups had a high nutritional quality, they were not the most expensive ones within their group. These subgroups, particularly milk, organ meats, and eggs, had a very good nutritional quality-to-price ratio. Vegetable fats, dried fruit, and nuts also showed good nutritional quality-to-price ratios. Interestingly, diets obtained using a computer to attain the whole set of nutritional recommendations at the lowest cost preferentially contained foods belonging to the groups and subgroups identified in the present study as having good nutritional quality-to-price ratios (36). This does not mean that low-income consumers should select only grains and starches and stay away from fruit, vegetables, and fish. On the contrary, the good quality-to-price ratio of grains and starches leaves a substantial amount of the budget for high-cost, nutrient-dense foods such as fruit, vegetables, and fish. Modeling studies using both cost and nutritional constraints showed that including important amounts of unrefined starches in the diet actually made it possible to fulfill all nutritional requirements for people on a moderate food budget (36). Interestingly, such modeled diets also included important amounts of fruit, vegetables, and fish.

The analysis of the link between diet cost and nutritional quality has been hampered for a long time by methodological limitations. Economists, who typically analyze household budgets surveys, lack information about individual consumption and about the nutritional composition of purchased foods. Conversely, nutritional epidemiologists lack information on the price of foods actually consumed by individuals. Associating a mean price to foods in food consumption surveys (as well as the mean nutritional composition associated with them) has allowed investigators to solve this methodological issue and to estimate the daily cost of each individual diet (15). Although this approach only roughly estimates individual expenditures, it seemed valid, in our study, to evaluate mean expenditures for food consumed at home, insofar as the mean daily cost estimated from the present data (4.7 €/d or $6.20/d) was very close to that from the last French household budget survey (37). The price of a given food varies according to stores, season, brand, size, packaging, and according to whether it is prepared at home or bought ready to eat. The use of a mean price partially hid this variability; although frequently consumed foods weighted higher in the mean price calculation. For instance, the mean price of green beans was closer to the price of the processed items rather than to that of the fresh ones. Likewise, the mean price of a given fruit was closer to the price in full season rather than to the price out of season.

Price variability within a single category of food may alter the nutritional quality-to-price ratio of foods considered individually. Actually, a British study showed that branded foods generally cost 2.5 times the price of economy-line foods, but do not contain more nutrients, so that the quantity of nutrients bought for one shilling of food was always clearly higher with economy-line products (38). We considered that this intrafood cost variability would not alter the nutritional quality-to-price hierarchy among main food groups, but this requires further investigation. Another possible drawback was the evolving nature of the indicators used to estimate the nutritional quality of food groups. The present NDS was based on 23 nutrients with a known RDA. Although only some of these nutrients are implicated in public health problems, the European Commission takes into account those nutrients that are scientifically recognized as having an effect on health. That list is still not finalized, especially insofar as nutritional problems are not the same in all countries because of different food habits, availability, and different enrichments and supplementation practices. We therefore preferred a more universal score than a country-specific score. On the other hand, one could also argue that our score does not consider enough different nutrients. Actually, several bioactive compounds, including polyphenols and some trace elements, were not included in the NDS, either because the nutrient composition database was not available or because the nutritional requirement was not yet defined. Furthermore, we calculated only those nutrients naturally present in foods and not those introduced by enrichment. This was done to avoid direct comparisons between a fortified food and a nonfortified food with a similar nutrient content.

The nutritional quality-to-price hierarchy presently found between food groups probably explains the positive association observed between the nutritional quality of the diet and its cost (15,18–20). Notwithstanding, the wide disparity of nutritional quality and prices observed within food groups is compatible with the fact that improving diet quality is not necessarily associated with increased diet costs in intervention studies implicating nutrition education (39–41). Our results suggest that, by preferentially selecting subgroups that have the highest nutritional quality-to-price ratio, healthy diets can be obtained at a moderate cost. However, such low-cost nutritionally adequate diets (39–41) deviated considerably from the typical food habits of the population (36). Although nutrition education could make such diets more attractive, they may not be palatable enough or socially acceptable. In addition, there is a threshold cost under which it is impossible to obtain a nutritionally adequate diet, estimated at ~3.5 €/d per adult in France (36) and at $116/wk for a 4-person family in the U.S. (42). Many studies have emphasized that food budgets of the poor are often under this threshold (16,17,36,43). The fact that food groups with the more favorable nutrient profile were also the more expensive sources of energy suggests that the present structure of food prices does not favor the adoption of food-based dietary guidelines, at least by low-income people.

Although nutritionally balanced diets can be obtained at limited cost (36,39–41), often they are neither palatable nor convenient. It is a major challenge for public health nutrition to link public health imperatives with economic realities of life in ensuring that nutritionally adequate and socially acceptable foods are affordable and available to all. A refinement of food and agriculture policies and food assistance programs is one potential strategy for change (44–46, and unpublished data by Z. Rambeloson, N. Darmon, and E. L. Ferguson). Effective dietary guidance must take into account both the nutrient profile of foods and their nutrient and energy costs. These considerations will allow consumers to identify and select optimal diets at an affordable cost.

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