

Are energy-dense foods really cheaper? Reexamining the relation between food price and energy density^{1–3}

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ABSTRACT

Background: The inverse relation between energy density (kcal/g) and energy cost (price/kcal) has been interpreted to suggest that produce (fruit, vegetables) is more expensive than snacks (cookies, chips).

Objective: The objective of this study was to show the methodologic weakness of comparing energy density with energy cost.

Design: The relation between energy density and energy cost was replicated in a random-number data set. Additionally, observational data were collected for produce and snacks from an online supermarket. Variables included total energy (kcal), total weight (g), total number of servings, serving size (g/serving), and energy density (kcal/g). Price measures included energy cost (\$/kcal), total price (\$), unit price (\$/g), and serving price (\$/serving). Two-tailed *t* tests were used to compare price measures by food category. Relations between energy density and price measures within food categories were examined with the use of Spearman rank correlation analysis.

Results: The relation between energy density and energy cost was shown to be driven by the algebraic properties of these variables. Food category was strongly correlated with both energy density and food price measures. Energy cost was higher for produce than for snacks. However, total price and unit price were lower for produce. Serving price and serving size were greater for produce than for snacks. Within food categories, energy density was uncorrelated with most measures of food price, except for a weak positive correlation with serving price within the produce category.

Conclusion: The findings suggest the relation between energy density and food price is confounded by food category and depends on which measure of price is used. *Am J Clin Nutr* 2009;90:1397–401.

INTRODUCTION

The inverse relation between energy density (kcal/g) and energy cost (\$/kcal) has been used to suggest that food price is related negatively to energy density (1–5). This relation has been interpreted to mean that produce (fruit, vegetables) is more expensive than energy-dense foods that contain added fats and sugars, such as snacks (cookies, chips) (1–9). In addition, this relation has been suggested as a reason for inadequate consumption of fruit and vegetables (1–9).

However, the relation between energy density and energy cost may have led to spurious conclusions, resulting from the presence of “kcal” in both the numerator of the explanatory variable (kcal/g) and the denominator of the dependent variable (price/kcal) (10, 11). This is an example of mathematical coupling, which refers to the

comparison of 2 variables that share a common component (in this case, “kcal”) and has often been identified as a methodologic problem (12–15). The problem with the specific type of coupling involved in the comparison between energy density and energy cost [division coupling (12)] results from the fact that, as energy density increases, kilocalories increase in the numerator of the ratio of kcal/g while simultaneously increasing in the denominator of the ratio of price/kcal. Therefore, if the ratio of price/g is constant relative to the change in kilocalories, then kcal/g and price/kcal will be inversely proportional entirely because of the algebraic properties of the ratios (16).

Consider the example in which one wishes to compare the energy cost (\$/kcal) of 2 different bags of chips (baked chips and fried chips), which have the same total price ($\$ = \$_{\text{baked}} = \$_{\text{fried}}$) and package weight ($g = g_{\text{baked}} = g_{\text{fried}}$) but differ in their energy content because of their different preparation methods ($2 \times \text{kcal}_{\text{baked}} = \text{kcal}_{\text{fried}}$). The energy densities of baked chips and fried chips then equal $\text{kcal}_{\text{baked}}/g$ and $2\text{kcal}_{\text{baked}}/g$, respectively, such that the energy density of fried chips is twice that of baked chips. In this example, total price ($\$_{\text{baked}} = \$_{\text{fried}}$) and unit price ($\$_{\text{baked}}/g_{\text{baked}} = \$_{\text{fried}}/g_{\text{fried}}$) of the 2 products are the same. However, the energy costs of baked chips and fried chips equal $\$/\text{kcal}_{\text{baked}}$ and $\$/2\text{kcal}_{\text{fried}}$, respectively, such that the energy cost of fried chips is half that of baked chips. This example shows how $\$/\text{kcal}$ varies inversely with kcal/g if the ratio of $\$/g$ is constant relative to the change in kilocalories, because of the presence of the same component, “kcal,” in both variables. The graph of this inverse relation is expected to resemble the L-shaped inverse relation curve of the general form, $y = a/x$, where a is a constant (17). Indeed, this is the shape of the relation between energy density and energy cost that has been reported in the literature (1–9).

The objective of this analysis was to show the methodologic weakness of comparing energy density and energy cost by replicating this relation in a data set of randomly generated numbers and, through the use of observational data, to compare

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this relation with those between energy density and alternative food price measures that did not involve division coupling.

METHODS

Data collection and variables

Randomly generated data

A random-number generator was used to create 3 variables, A, B, and C, which represent “kilocalories,” “grams,” and “total price,” respectively. Each variable was made to contain 100 values drawn independently from a uniform distribution between 0 and 1. From these randomly generated variables, 2 ratio variables, A/B and C/A, were created to represent “energy density” and “energy cost,” respectively.

Observational data

Observational data were collected on food products available on a website for a supermarket chain in the mid-Atlantic region of the United States (18). A criterion sampling method was used such that for each produce type (eg, apples, oranges, lettuce, broccoli) and snack brand (eg, “A” brand chocolate cookies, “B” brand corn chips), each item with the lowest unit price (\$/g) for which all necessary information was available was included. For example, if the apple product with the lowest unit price was a 5-lb (2.3-kg) bag of apples, then this product was included.

Variables included total weight as packaged (g), total kilocalories as packaged, total number of servings as packaged, serving size (g/serving), and energy density (kcal/g). Food price measures included energy cost (\$/kcal), total price as packaged (\$), unit price (\$/g), and serving price (\$/serving). A dichotomous food category variable was created to classify foods as either a produce or a snack product. Information for variables was obtained from the supermarket website, the nutritional facts panel (for snacks), and the US Department of Agriculture (USDA) search tool, What’s in the Foods You Eat 3.0, based on the Food and Nutrient Database for Dietary Studies 3.0 (for produce) (19). Food weights were based on the edible portion of the food (20, 21). Serving size was based on standardized quantities (20, 21).

Statistical analysis

Scatter plots were used to examine the relation between energy density and energy cost in the observational data and the relation between the analogous variables, A/B and C/A, in the randomly generated data set. Additional analysis, with the use of the observational data, included energy density and food category as predictor variables and the 4 food price measures (energy cost, total price, unit price, serving price) as outcome variables. Two-tailed *t* tests (assuming unequal variances where appropriate) were used to compare characteristics by food category. Within food categories, the relations between energy density and total price, unit price, and serving price were examined with use of Spearman rank correlation analysis. STATA version 9.2 for Windows (Stata Corp, College Station, TX) was used for all analyses.

RESULTS

Means (SE) for the variables A, B, and C in the random data, which represent kilocalories, weight (g), and total price (\$), respectively, were each 0.5 (0.3). Means (SE) for the variables A/B and C/A were 4.6 (1.6) and 2.3 (0.4), respectively. The characteristics of the observational data are summarized in **Table 1**. Mean total weight as packaged was significantly greater for produce than for snacks. Mean total kilocalories as packaged and the total number of servings as packaged were significantly greater for snacks than for produce. Mean serving size was more than 3-fold larger for produce than for snacks. Mean energy density was 4.2 (0.1) kcal/g higher for snacks than for produce. Mean energy cost was 0.02 (0.003) \$/kcal greater for produce than for snacks.

Scatter plots that depict the relation between A/B (energy density) and C/A (energy cost) for the randomly generated data are shown in **Figure 1** alongside the relation between energy density and energy cost for foods in the observational data. Because the components in the random data set were drawn independently, there should be no true relation between the variables. However, the same relation that has been shown in previous studies between energy density and energy cost (that of the curve, $y = a/x$) is revealed in both the observational data and the randomly generated data, which shows that this relation is primarily due to the presence of kilocalories in both the

TABLE 1
Characteristics of observational data by food category¹

	Total (n = 82)	Produce (n = 40)	Snacks (n = 42)	P value ²
Product characteristics				
Total weight (g)	351.9 ± 46.1	472.8 ± 563.1	236.7 ± 121.2	0.01
Total energy (kcal)	676.4 ± 73.3	233.7 ± 400.6	1098.0 ± 587.2	<0.0001
Total no. servings	8.1 ± 0.6	6.7 ± 5.4	9.4 ± 5.2	0.02
Energy density (kcal/g)	2.6 ± 0.3	0.5 ± 0.3	4.6 ± 0.5	<0.0001
Serving size (g)	53.6 ± 5.0	82.7 ± 50.9	25.9 ± 5.0	<0.0001
Food price measures				
Energy cost (\$/kcal)	0.01 ± 0.002	0.02 ± 0.003	0.004 ± 0.0003	<0.0001
Total price (\$)	2.8 ± 0.2	2.5 ± 0.3	3.1 ± 0.1	0.045
Unit price (\$/g)	0.01 ± 0.001	0.009 ± 0.001	0.02 ± 0.001	0.0001
Serving price (\$/serving)	0.5 ± 0.1	0.7 ± 0.1	0.4 ± 0.04	0.02

¹ All values are means ± SEs.

² Differences between produce and snacks (2-tailed *t* tests assuming unequal variance where appropriate).



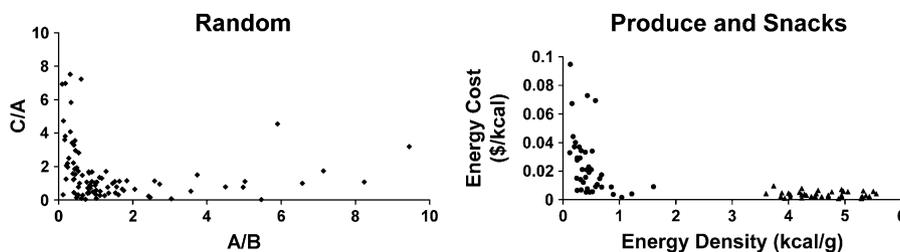


FIGURE 1. The relation between A/B (energy density) and C/A (energy cost) for the randomly generated data and between energy density (kcal/g) and energy cost (\$/kcal) for produce (●; $n = 40$) and snacks (▲; $n = 42$) in the observational data.

independent and dependent variables. The figure also suggests that the 2 food categories in the observational data represent 2 distinct populations that require separate analyses.

To illustrate further how the relation between energy density and energy cost is the result of division coupling, this relation can be compared with those between energy density and measures of food price in which “kcal” is not a component. The relations between energy density and total price (\$), unit price (\$/g), and serving price (\$/serving), for the same observational data used in Figure 1, are shown in Figure 2. Although the same data are used in both figures, the relations shown in Figure 2 differ dramatically from those in Figure 1. That the 2 food categories represent 2 distinct populations that require separate analyses is also suggested in Figure 2.

The 2 distinct populations depicted in Figures 1 and 2 suggest that food category confounds the relation between energy density and food price measures. The regression of energy density onto food category in the observational data revealed $R^2 = 0.96$, which suggests that food category explained nearly all of the variance in energy density.

To further investigate possible confounding, mean food price measures were compared by food category (Table 1). These results show that all measures of food price are significantly related to food category. Specifically, mean total price and unit price are lower for produce than for snacks, whereas mean serving price is lower for snacks than for produce. Mean energy cost is lower for snacks than for produce because of division coupling in the relation between kcal/g and \$/kcal.

The relations between energy density and food price measures within food categories were examined to investigate the possi-

bility of an interaction between the variables (Figure 3). Within the produce food category, there was a weak positive correlation between energy density and serving price. There were no other significant correlations between energy density and food price measures within food categories.

DISCUSSION

This analysis showed that energy density (kcal/g) and energy cost (\$/kcal) are inversely proportional, at least in part because of division coupling, whereby “kcal” is present in both the numerator of the independent variable (energy density) and the denominator of the dependent variable (energy cost). In other words, energy cost is inversely proportional to energy density, and the energy cost of snacks is lower than that of produce, primarily because the unit price (\$/g) is constant relative to the change in kilocalories. This inverse relation was also shown in a data set of randomly generated numbers, which shows how any 2 variables, A/B and C/A, are expected to be inversely proportional as long as the ratio of C/B is relatively constant and the error term is not sufficiently large that the underlying mathematical relation is obscured. Analogously, fruit and vegetables have been shown to have lower nutrient cost (\$/nutrient) than do snacks (22) as a result of their high nutrient density (nutrients per unit) (22, 23). The analysis presented in this article shows that relations between variables that involve mathematical coupling should be interpreted with extreme caution.

The relations between energy density and food price measures were shown to be confounded by food category. Food category explained 96% of the variance of energy density, such that energy

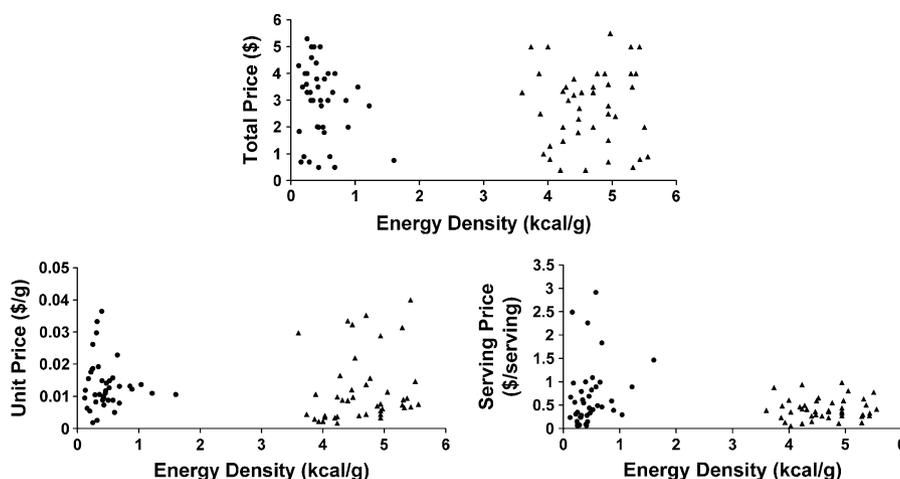


FIGURE 2. Relations between energy density and total price, unit price, and serving price for produce (●; $n = 40$) and snacks (▲; $n = 42$) in the observational data.

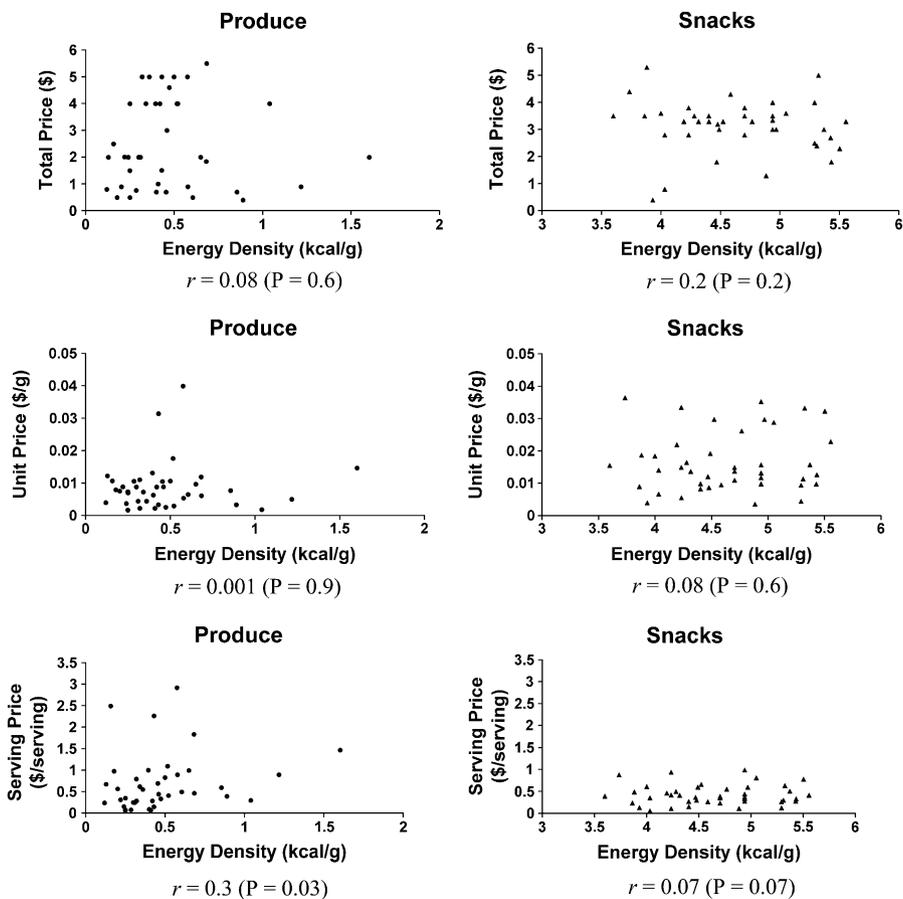


FIGURE 3. Relations between energy density and food price measures within food categories (●, produce, $n = 40$; ▲, snacks, $n = 42$) in the observational data. Spearman rank correlation coefficients (r) and P values for the test of the hypothesis of no correlation are given.

density was ≈ 4.2 kcal/g higher for snacks than for produce. In addition, all food price measures were significantly related to food category. Within food categories, energy density was not significantly correlated with food price measures, except for a weak, positive correlation with serving price within the produce category. This confounding by food category suggests that future analysis of the relation between energy density and food price should include food category as an independent variable to prevent biased estimation of the effect of energy density on food price.

These results also show how the relative price of produce and snacks depends on the measure of price. Because of the division coupling present in the relation between energy density and energy cost, snacks, whose energy density is >9 times that of produce, were shown to have a lower average energy cost than did produce. However, the average total package price and unit price of produce were lower than those of snacks, whereas the average serving price was lower for snacks than for produce. The findings regarding serving price are not surprising because the serving size of produce was >3 times larger by weight than that of snacks, and it would be reasonable to pay more for more food. These findings suggest that the relative price of produce and snacks cannot be determined on the basis of energy cost alone; rather, the relative price depends on the measure of price that is used.

Similar to the method used in previous studies that reported an inverse relation between energy density and energy cost (2, 3), the food products in this analysis were selected from only one su-

permarket. Thus, the results from this convenience sample are not representative nationally. A more thorough investigation of the cost of produce from all retail outlet types conducted by the USDA Economic Research Service showed that fresh fruit and vegetables cost an average of \$0.18 and \$0.12/serving, respectively, and most analyzed produce costs \leq \$0.25/serving (24). That study showed how the entirety of the daily recommended 3 servings of fruit and 4 servings of vegetables could be purchased for \$0.64, which accounts for only 12% of daily food expenditures of the lowest-income households, and that several combinations of the recommended number of servings of fruits and vegetables could be purchased for \leq \$1/d (24). These findings suggest that, on the basis of serving price, the price of fruit and vegetables may not be a significant barrier to their purchase and intake. However, an extensive literature suggests that lower-income populations face differential food prices than do those of higher-income populations. Evidence indicates that poor inner-city consumers pay higher food prices (measured as the total price of a market basket of food products) than do higher-income suburban consumers, largely because of their lack of access to larger chain grocery stores, which tend to offer lower prices and a more diverse, high-quality selection of products than do non-chain stores (25–27). Future research regarding the relative price of produce should try to account for these differences.

It has not yet been determined whether energy cost is a meaningful variable for evaluating food price or purchasing



decisions (10, 11). Whether consumers are aware of the energy cost of food products is debatable. Such information is not readily available, either in food databases (20) or at the point of purchase, where only total price and unit price are typically provided. Energy cost must be calculated by dividing total price by the total number of calories. Furthermore, the calorie content of produce is often not provided at the point of purchase, and for packaged foods, this amount must be calculated from the nutritional facts panel by multiplying kcal/serving by the total number of servings per package. It is unknown whether consumers use the nutritional facts panel in this way or perform the steps necessary to determine energy cost, and it is unlikely that consumers make purchasing decisions on the basis of unknown price information. Until energy cost is validated as an appropriate measure of food price, future research regarding the relative price of produce should make use of validated measures of price that are more commonly used in the relevant economics literature, such as serving price or the total price of a market basket of food products (24–28).

In this analysis, food category confounded the static relation between energy density and food price measures. Therefore, failure to control for food category in this relation will lead to biased estimates of the bivariate relation between energy density and food price. Implicit in this discussion is the assumption that food price determines purchasing behavior, and that the relative price of food categories determines the quantity of foods in these categories that are purchased. However, food categories differ in numerous ways other than food price (eg, taste, convenience, health, availability), which may also influence purchasing behavior. Available evidence suggests that food choice in developed countries is an enormously complex behavior that results from the personal management of a multidimensional value system that involves the negotiation of intricate personal preferences, which in turn are influenced by numerous social, personal, and environmental factors (29–31). Therefore, failure to account for these confounding variables may lead to spurious conclusions regarding the bivariate relation between food price and purchasing behavior.

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