Nutrient density: principles and evaluation tools1–3

Adam Drewnowski and Victor L Fulgoni III

ABSTRACT
Nutrient profiling is the technique of rating or classifying foods on the basis of their nutritional value. Foods that supply relatively more nutrients than calories are defined as nutrient dense. Nutrient profile models calculate the content of key nutrients per 100 g, 100 kcal, or per serving size of food. For maximum effectiveness, nutrient profile models need to be transparent, based on publicly accessible nutrient composition data, and validated against independent measures of a healthy diet. These rigorous scientific standards were applied to the development of the Nutrient-Rich Foods (NRF) family of nutrient profile models. First, the NRF models included nutrients to encourage as well as nutrients to limit. Second, NRF model performance was repeatedly tested against the Healthy Eating Index (HEI), an independent measure of a healthy diet. HEI values were calculated for participants in the 1999–2002 NHANES. Models based on 100 kcal and serving sizes performed better than those based on 100 g. Formulas based on sums and means performed better than those based on ratios. The final NRF9.3 index was based on 9 beneficial nutrients (protein; fiber; vitamins A, C, and E; calcium; iron; potassium; and magnesium) and on 3 nutrients to limit (saturated fat, added sugar, and sodium). Higher NRF9.3 scores were associated with lower energy density and more nutrient-rich diets. The nutrient density of foods, paired with a comprehensive program of consumer education, can become the foundation of dietary recommendations and guidelines. Am J Clin Nutr 2014;99(suppl):1223S–8S.

PRINCIPLES OF NUTRIENT PROFILING

The intent of composite nutrient density scores is to capture the multiple nutritional attributes of a given food (2, 3, 8). Wholesome, nutrient-rich foods receive high scores, whereas foods that provide calories but few nutrients score lower (2). By including multiple beneficial nutrients to encourage, balanced nutrient profile models shift the emphasis from “bad” nutrients to “good” and “better” foods. Nutrient profiling exemplifies a positive way to convey vital information about nutritional attributes of foods and beverages to the consumer (2, 3, 6, 7).

For nutrient profiling to remain a science, it needs to follow scientific rules (13). Thus far, the procedures for developing, testing, and validating nutrient profile models have not been standardized (14, 15). These include, but are not limited to, the selection of relevant nutrients, the choice of reference daily values overall, and improved health outcomes (3).

Nutrient profiling can also help identify foods that are nutrient rich, affordable, and sustainable. The inclusion of food prices in nutrient density calculations has allowed researchers to create new metrics of affordability and to identify those foods that provide the most nutrients per penny (8, 9). This econometric approach to nutrient profiling (10, 11) was among the first to explore the interrelations between nutrient density, energy density, and energy cost. More recent studies have taken nutrient profiling in a different direction, exploring the relation between the nutrient density of foods and their carbon footprint, as determined by greenhouse gas emissions from life-cycle analysis (12).

Nutrient profiling techniques developed for individual foods can also be applied to meals, menus, and total diets. By showing how the nutrient density concept applies to total diet quality and the economics of food choice behavior, nutrient profiling provides a ready way to put the Dietary Guidelines for Americans and MyPlate into practice (6, 7).
values, and the basis of calculation: 100 kcal, 100 g, or serving size (14, 15). Nutrient profile models also need to be tested against other food attributes (14) and need to be validated with respect to independent measures of a healthy diet (3, 16).

The basic principles of nutrient profiling have been laid out before (1–3), stressing the need for objectivity, transparency, simplicity, and validation. Briefly, nutrient profile models had to be based on objective nutrition science; they had to be totally transparent and based on open-source data and published algorithms. Nutrient composition databases had to be of high quality and available from public sources. Simple algorithms were preferable to more complex ones, and alternative models were to be tested against other food attributes, notably energy density and energy cost (14, 15). Most important, alternative models were to be validated against independent measures of a healthy diet and, wherever possible, compared with selected health outcomes (16). Here, nutrient composition data for individual foods and beverages had to be supplemented with population-based data on diets and health.

NUTRIENT-RICH FOODS INDEX

The development of the Nutrient-Rich Foods (NRF)4 Index closely followed the regulatory guidelines in the United States, as formulated by the US Food and Drug Administration (FDA) (1, 2). In particular, the selection of beneficial nutrients followed federal policies and standards (1, 2). Foods are defined as “healthy” by the FDA on the basis of their content of protein, fiber, vitamins A and C, calcium, and iron. Foods are disqualified by the FDA from carrying nutrition and health claims if they contain more than specified amounts of fat, saturated fat, trans fat, cholesterol, or sodium. Additional NRF nutrients were suggested by the 2005 Dietary Guidelines (17), which identified potassium, magnesium, and vitamin E as shortfall nutrients in the US diet. The goal was to produce a nutrient density score that would be consistent with the Nutrition Facts panel and could be used for front-of-pack labeling.

One way to visualize the nutrient density of foods is to determine the percentage daily value (%DV) of different nutrients per serving, always in relation to calories. Thus, a 6-ounce serving of plain skinned-milk yogurt supplied <5% DV of daily calories but >30% DV of calcium, >25% DV of phosphorus, >10% DV of potassium, and zinc, and >5% DV of magnesium. Similarly, a fruit-flavored low-fat yogurt provided <10% of dietary energy but >25% DV of calcium, >20% DV of phosphorus, close to 15% DV of protein, and >10% DV of potassium. Given the favorable nutrients-to-calories ratio, a yogurt can be defined as a nutrient-rich food.

Nutrient profiling aims to provide an overall nutrient density score on the basis of several nutrients. Reference DVs, based on a 2000-kcal diet, were obtained for protein (50 g); fiber (25 g); vitamins A (5000 IU), C (60 mg), and E (30 IU); calcium (1000 mg); iron (18 mg); potassium (3500 mg); and magnesium (400 mg). Nutrient contents of foods were converted to %DVs per reference amount and then capped at 100% DV so that foods containing very large amounts of a single nutrient would not obtain a disproportionately high index score (1). For nutrients to limit, maximum recommended values were 20 g for saturated fat, 125 g for total sugar, 50 g for added sugar, and 2400 mg for sodium. All scores were initially calculated per 100 kcal, per 100 g, or per serving size of food (14, 15).

The FDA-mandated serving sizes are otherwise known as reference amounts customarily consumed (RACCs). The FDA uses 139 different RACC values that are set lower for energy-dense sugar (4 g), fats and oils (15 g), and cheeses (30 g) than for meats (85 g), vegetables and fruit (120 g), yogurts (220 g), or milk, juices, and other beverages (240 g).

The family of NRF models was developed and tested by using the open-access USDA Food and Nutrient Database for Dietary Studies (FNDDS), which is used to code, process, and analyze the What We Eat in America dietary intake data (18). The FNDDS files include detailed food descriptions, food portions and weights, nutrient descriptions, and links to the USDA Standard Release nutrient composition databases (19). The FNDDS data now include vitamin D but need to be supplemented with the added sugar content of foods. RACC values were developed for 5906 foods in the FNDDS database.

In developing the family of NRF indexes, we first created nutrient-rich subscores based on a variable number n of beneficial nutrients (NRn). The NRn components were expressed as unweighted sums of %DVs (SUM) or as means of %DVs (MEAN) per reference amount. The negative limited nutrient score (LIM) component was based on 3 nutrients only (saturated fat, added sugar, and sodium), which were also expressed as %DVs per reference amount.

NRF indexes were calculated as the arithmetic differences between the positive (NRn) and the negative (LIM) components. A ratio-based algorithm was also tested. Food scores obtained by using alternative NRn, LIM, and NRF indexes were then compared with the energy density (kcal/100 g), energy cost (S/100 kcal), and nutrient content of the food. Different algorithms and calculation methods developed in past research (14, 15) are shown in Table 1.

Index calculations based on 100 kcal and 100 g or serving size gave rise to very different results. Foods that benefited the most from the 100-kcal calculation were low-energy-dense vegetables and salad greens, such as spinach, lettuce, endive, watercress, and cabbage. Foods that benefited more from the 100-g calculation were energy-dense foods, notably nuts and seeds, protein powder, and fortified cereals. RACC-based calculations benefited foods that were consumed in amounts >100 g, including fruit and fruit juices, cooked vegetables and juices, milk and yogurts, and other beverages and mixed foods. By contrast, foods that were consumed in amounts <100 g, such as nuts and seeds, and fortified cereals received lower scores under a RACC-based system.

The LIM subscore performed differently when calculated per 100 g or per RACC. The most pronounced differences were obtained for fats, mixed foods, and beverages. Calculations based on 100 g strongly penalized foods that contained saturated fat and sodium but that were regularly consumed in serving sizes well below 100 g. RACC-based LIM scores penalized beverages that contained added sugar and were consumed in 240-g portion sizes, as opposed to 100 g. A system based on 100 g was more lenient toward sugar-sweetened beverages than a system based on serving size (240 g in the United States).

4 Abbreviations used:DV, daily value; FDA, US Food and Drug Administration; FNDDS, Food and Nutrient Database for Dietary Studies; HEI, Healthy Eating Index; LIM, limited nutrient score; NRF, Nutrient-Rich Foods (index); NRn, subscore based on a variable number n of beneficial nutrients; RACC, reference amount customarily consumed.
VALIDATION OF NUTRIENT PROFILE MODELS

Choosing the best nutrient profile model from among multiple alternatives is another scientific challenge (2, 19). In some validation studies, food rankings generated by different models were compared with mean ratings for the same foods generated by health professionals or by expert panels (20). Only 3 published, fully transparent models have been validated with respect to objective diet quality measures: the French SAIN/LIM (16), the British FSA-Ofcom model (19), and the NRF9.3 index (3).

In the NRF9.3 validation study (3), each food reported by subjects in the NHANES 1999–2002 was scored by using NR


TABLE 1
Algorithms for NRn and LIM subscores and for the composite NRF nutrient profile models

<table>
<thead>
<tr>
<th>Model</th>
<th>Algorithm</th>
<th>Reference amount</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subscores NRn</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| NRn_100 g            | \(\sum_{i=1}^{n} (\text{Nutrient}_i / \text{DV}_i) \times 100\)           | 100 g            | Nutrient\textsubscript{i} = content of nutrient \textsubscript{i} in 100 g
| NRn_100 kcal         | \((\text{NRn}_100 \text{ g/ED}) \times 100\)                            | 100 kcal         | ED = energy density (kcal/100 g)                                       |
| NRn_RACC             | \((\text{NRn}_100 \text{ g/100}) \times \text{RACC}\)                   | Serving          | RACC = FDA serving size                                                 |
| Subscores LIM        |                                                                           |                  |                                                                         |
| LIM_100 g            | \(\sum_{i=1}^{3} (\text{L}_i / \text{MRV}_i) \times 100\)               | 100 g            | L\textsubscript{i} = content of limiting nutrient \textsubscript{i} in 100 g
| LIM_100 kcal         | \((\text{LIM}_100 \text{ g/ED}) \times 100\)                           | 100 kcal         | ED = energy density (kcal/100 g)                                       |
| LIM_RACC             | \((\text{LIM}_100 \text{ g/100}) \times \text{RACC}\)                   | Serving          | RACC = FDA serving size                                                 |
| Composite NRFn0.3    |                                                                           |                  |                                                                         |
| NRFn.3_sum           | \text{NRn}_100 \text{ kcal} – \text{LIM}_100 \text{ kcal}              | 100 kcal         | Difference between sums                                                 |
| NRFn.3_mean          | \text{NRn}/\text{LIM}/3                                                  | 100 kcal         | Difference between means                                                |
| NRFn.3_ratio         | \text{NRn}/\text{LIM}\textsuperscript{2}                                | None             | Ratio                                                                   |

\textsuperscript{1} FDA, US Food and Drug Administration; LIM, limited nutrient score; NRF, Nutrient-Rich Foods; NRn, subscore based on a variable number \(n\) of beneficial nutrients; RACC, reference amount customarily consumed.

\textsuperscript{2} \text{NRn}_100 \text{ g/LIM}_100 \text{ g} was equivalent to \text{NRn}_100 \text{ kcal/LIM}_100 \text{ kcal} and to \text{NRn}_\text{RACC/LIM}_\text{RACC}.

As shown in Figure 1, the NRF9.3 nutrient profile model based on 100 kcal and on RACC explained the most variation in HEI (44.5\% of the variance). The NRF9.3 model was based on protein; fiber; vitamins A, C and E; calcium; iron; potassium; and magnesium. These are the nutrients of concern as identified by US government agencies and expert panels. The 3 nutrients to limit were saturated fat, added sugars, and sodium.

NRF indexes that included beneficial nutrients as well as nutrients to limit performed better than did indexes that were based on nutrients to limit only. The LIM score predicted \(\sim 32\%\)

FIGURE 1. Linear regressions of LIM and NRFn.3 models on the Healthy Eating Index 2005 calculated for participants aged \(>4\) y in the NHANES 1999–2002 database. Data are from reference 3 (Table 2, page 1551). LIM, limited nutrient score; NRF, Nutrient-Rich Foods; RACC, reference amount customarily consumed.
of the variance in HEI. Maximum variance in HEI was explained with the use of 6 or 9 beneficial nutrients; index performance actually declined with the inclusion of additional vitamins and minerals. The data confirmed previous studies (14, 15) showing that increasing the number of nutrients above 10 in a nutrient profile model provided little or no additional benefit in predicting overall diet quality.

In other analyses, NRF indexes based on 100 kcal (418 kJ) performed similarly to indexes based on RACC. Algorithms based on sums or means of nutrient-based subscores performed better than did algorithms based on dividing one subscore by another (eg, reference 21). Ratio-based scores are inherently problematic and may need to be radically transformed before they will be useful to consumers.

The NRF9.3 index was an unweighted score. Instances of weighted nutrient density scores do exist, and weights have been justified in a variety of ways: biological quality of nutrients, their bioavailability, their ubiquity in the food supply, and relative influence to health. In past studies, weighting has been based on expert opinion. However, new analyses point to novel approaches to weighting nutrients for inclusion in nutrient profiling schemes based on their estimated importance in the population diet (22).

IDENTIFYING NUTRIENT-DENSE FOODS

As shown in Figure 2, the median nutrient density of foods, as rated by the NRF system, differed across the major USDA food groups (2, 3). The highest scores were obtained by low-energy-dense vegetables and fruit, followed by legumes and eggs. Fats and oils, grains, and sweets had higher energy density and lower per-calorie nutrient content. Within food groups, whole grains scored higher than refined grains and 100% fruit juices scored higher than soft drinks. Lower-fat dairy products, including fluid milk and yogurts, had higher scores than did products containing more saturated fat.

Individual NRF9.3 scores showed more variance than did median scores for a given food category or food group. Thus, skimmed milk scored 123 on the NRF9.3 score, chocolate skimmed milk scored 56, milk with 2% fat (semiskimmed) scored 43, and whole milk 38. Plain nonfat yogurt scored 94, whereas vanilla-flavored nonfat yogurt scored 38. Lower NRF scores were obtained for ice cream and for some dairy desserts.

BUILDING HEALTHIER DIETS

Studies have shown that nutrient density is an accurate marker of healthy diets, distinguishing between diets that are energy dense and those that are nutrient rich (11). Participants in the 1999–2002 NHANES were then assigned to quintiles on the basis of their dietary NRF9.3 scores. Persons in the top quintile of NRF9.3 scores consumed more beneficial nutrients, including some that were not part of the model (vitamin B-12 and zinc). Their diets were also characterized by more whole grains, low-fat dairy, vegetables, and fruit. However, the more-nutrient-dense diets tended to be more expensive. As shown in Figure 3, the top NRF9.3 quintile was associated with significantly higher per-calorie diet costs compared with the lowest NRF9.3 quintile (4).

These findings, associating different nutrient density scores with diet quality measures, have implications for dietary guidance. Quintiles of NRF9.3 scores translated easily into a consumer-friendly 5-point scale (24). Preliminary data suggest that each point on a 5-point scale was approximately equivalent to 10% DV, a criterion favored by the FDA in regulating nutrition and health claims.

Focusing only on nutrients to limit may not necessarily guide consumers toward healthier options, especially if those options are associated with lower enjoyment and higher cost. However, a focus on nutrient density may influence healthier choices, as shown in a pilot intervention trial (25). However, more studies are needed.
needed to confirm that nutrient density signposting can lead to positive changes in consumer food purchase behavior (26).

Nutrition experts agree that the US diet tends to be energy dense but nutrient poor (1). Increasing the consumption of lower-energy but nutrient-rich foods would achieve the twin objectives of reducing daily calories and increasing the overall nutrient density of the diet. Identifying foods that are affordable, sustainable, and nutrient rich is the goal of nutrient profiling (2–4). The NRF and other nutrient profiling models were intended to promote the consumption of fewer calories and more beneficial nutrients (2–4).

Paradoxically, much dietary advice emphasizes what nutrients to avoid. The notion of what constitutes a “healthful” food seems to be based on the absence of saturated fat, added sugars, and sodium rather than on the presence of beneficial nutrients that the food contains (1). As witnessed by dramatic increases in the rates of obesity and diabetes over the past 20 y, such negative dietary advice has not been effective. A more positive approach to dietary guidelines may prove to be more successful in the long term (6, 7).

Translating the concept of nutrient density into healthier everyday diets requires the combination of nutrient profiling methods with other strategies for improving food habits and health. Studies need to address food patterns and overall diet quality, especially in relation to sustainability and to monetary cost (23, 24) and greenhouse gas emissions (12). The NRF9.3 is the only index that can help identify foods of good nutritional quality for their price: a validation study with linear programming. J Nutr 2008;138:1107–13.


It is time for a positive approach to dietary guidance using nutrient density as a basic principle. J Nutr 2009;139:1198–202.


It is time for a positive approach to dietary guidance using nutrient density as a basic principle. J Nutr 2009;139:1198–202.


