Development and Validation of the Nutrient-Rich Foods Index: A Tool to Measure Nutritional Quality of Foods[1–3]

Victor L. Fulgoni III,[4]* Debra R. Keast,[5] and Adam Drewnowski[6]

[4]Nutrition Impact, LLC, Battle Creek, MI 49014; [5]Food and Nutrition Database Research Inc., Okemos, MI 48864; and [6]Center for Public Health Nutrition, School of Public Health, University of Washington, Seattle, WA 98195

Abstract

Ranking and/or classifying foods based on their nutrient composition is known as nutrient profiling. Nutrition quality indices need to be tested and validated against quality of the total diet. A family of nutrient-rich foods (NRF) indices were validated against the Healthy Eating Index (HEI), an accepted measure of diet quality. All foods consumed by participants in NHANES 1999–2002 studies were scored using NRF*n*.3 (where $n = 6–15$) indices based on unweighted sums, means, and ratios of percent daily values (DV) for nutrients to encourage (*n*) and for nutrients to limit (LIM) (3). Individual food scores were calculated based on 100 kcal (418 kJ) and FDA serving sizes [reference amounts customarily consumed (RACC)]. Energy-weighted food-based scores per person were then regressed against HEI, adjusting for gender, age, and ethnicity. The measure of index performance was the percentage of variation in HEI (R^2) explained by each NRF score. NRF indices based on both nutrients to encourage and LIM performed better than indices based on LIM only. Maximum variance in HEI was explained using 6 or 9 nutrients to encourage; index performance actually declined with the inclusion of additional vitamins and minerals. NRF indices based on 100 kcal (418 kJ) performed similarly to indices based on RACC. Algorithms based on sums or means of nutrient DV performed better than ratio-based scores. The NRF9.3 index, based on 9 nutrients to encourage and 3 LIM per RACC and per 100 kcal, explained the highest percentage of variation from HEI and could be readily expected to rank foods based on nutrient density. J. Nutr. 139: 1549–1554, 2009.

Introduction

Diet quality indices assess the overall nutritional quality of the total diet; in contrast, food nutritional quality indices are intended to measure nutrient quality of individual foods (1–6). The science of ranking and/or classifying foods based on their nutrient composition has become known as nutrient profiling (7,8). Much of the impetus for nutrient profiling has come from the European Union, where nutrition and health claims will be introduced in 2012 (9). Whereas foods with acceptable profiles will be allowed such claims, those with unacceptable profiles will be disqualified. Specific criteria to identify acceptable/unacceptable profiles are still being debated (10,11). In the US, nutrition and health claims have been permitted for some time (12). However, foods that exceed predefined levels of total fat, saturated fat, cholesterol, or sodium are disqualified from carrying a health claim (13,14). Additionally, to be considered "healthy" by the FDA, foods must not only meet the criteria above but must also provide ≥10% of the daily value (DV)[7] of protein, fiber, vitamin A, vitamin C, calcium, or iron.

A number of existing nutrient profile models or nutrition quality indices have recently been developed by academic researchers, regulatory bodies, and the food industry (5,15–22). Some of those indices are based on only nutrients to encourage, others on only nutrients to limit (LIM), or on some combination of both. Rankings generated by existing models have been compared with each other and correlated with expert and/or consumer opinion (10,23–26). In rare cases, food rankings obtained from such models have been validated against independently obtained measures of a healthy diet (24).

If nutrient profiling is to remain a science, it needs to follow science-driven rules. First, indices of food nutritional quality need to be based on the prevailing scientific knowledge about diets and health. Such indices should take into account nutrients known to be beneficial to health as well as LIM based on scientific consensus or authoritative reports. Creating a composite nutritional quality index for individual foods raises a

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* To whom correspondence should be addressed. E-mail: vic3rd@aol.com

[7] Abbreviations used: DV, daily value; HEI, Healthy Eating Index; LIM, nutrients to limit; NRF, nutrient-rich foods; NRF*n*.3, nutrient-rich foods index, where *n* equals a range of nutrients to encourage and 3 equals the number of nutrients to limit; RACC, reference amount customarily consumed.

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number of methodological issues (9), including the selection of index nutrients, the choice of reference DV, and the choice of reference amounts: 100 g, 100 kcal,[8] or serving size (4). Most important, all indices need to be validated against an accepted independent measure of diet quality. The Healthy Eating Index (HEI), recently updated by the USDA (27), is a measure of diet quality based on compliance with the 2005 Dietary Guidelines for Americans and MyPyramid. HEI is based on a 100-point scale and awards points for adequate (or moderate) consumption of various food and nutrient components. The validity of HEI as a diet quality measure has been established following extensive analyses (28,29). The objective of this study was to develop food nutritional quality indices for individual foods, test their performance, and correlate food scores with independent measures of a healthy diet. Percent of variation in HEI explained (R^2) was the key criterion of index performance. The indices that best predicted variation in HEI were then further characterized by examining scores on a food group basis.

Methods

The algorithms evaluated. The nutrients in the algorithms evaluated were based on multiple criteria. The 2005 Dietary Guidelines for Americans have identified additional nutrients of concern that are underrepresented in the typical U.S. diet (30). In adults, these are fiber, vitamins A, C, and E, calcium, potassium, and magnesium. For children and adolescents, nutrients of concern are fiber, vitamin E, calcium, potassium, and magnesium. For specific population groups (30), they include vitamin B-12, iron, folic acid, and vitamin D. The FDA defines "healthy" foods as including 1 of 6 nutrients: protein, fiber, vitamins A and C, calcium, or iron.

Based on recent work (31,32), a number of nutrient-rich foods (NRF) indices were selected for testing and validation against HEI scores. The composite indices, described as NRF*n*.3, were based on *n* nutrients to encourage and on 3 LIM (**Table 1**). Whereas the number of nutrients to encourage was variable (n = 6–15), the 3 LIM were always the same: saturated fat, added sugar, and sodium. We also evaluated the impact of total sugars replacing added sugars.

Previous efforts on nutrient profiling show that fats, sugars, and sodium are the commonly recommended LIM (4,17). Past systems were based on fat, saturated fat, cholesterol, and sodium (33); total and saturated fats, *trans* fats, sugars, and sodium (10,11); energy, saturated fat, total sugar, and sodium (7,20,34); or saturated fats, added sugars, and sodium (35). Our previous work using factor analysis indicated that energy, total fats, and saturated fats were highly correlated with each other, as were total and added sugars. Sugars were not linked to dietary energy and sodium was independent of sugars and energy/fat. Therefore, including both energy and fat content was superfluous, as was the inclusion of both total and saturated fat. In this study, we chose to define our LIM subscore as saturated fat, added sugar, and sodium (4,17,35). Including *trans* fat was not an option, because NHANES food and dietary data does not as yet contain *trans* fat values; given the limitations on *trans* fat data, we could not validate NRF algorithms with alternative HEI (36).

Indices were calculated as: *1*) the sum of nutrients to encourage minus the sum of LIM; *2*) the mean of nutrients to encourage minus the mean of LIM; and *3*) the ratio of nutrients to encourage:LIM. In all indices, nutrient amounts were calculated as a percent of reference DV. Reference DV for a number of vitamins and minerals are summarized elsewhere (37). For LIM, reference values were 20 g of saturated fat, 50 g of added sugar (125 g for total sugars), and 2400 mg of sodium in a 2000-kcal/d diet, as based on a variety of authoritative sources (37–39).

Validation approach. Data from NHANES 1999–2002 were used as the principal data source for testing and validating the NRF algorithms. NHANES, an ongoing data collection initiative conducted by the National Center for Health Statistics of the CDC, is designed to collect information about the health and diet of a cross-sectional, nationally representative sample of the noninstitutionalized civilian population in the US. Additional information pertaining to the NHANES 1999–2002 survey design, survey methodology, and public use of the data has been posted on the NHANES Web site (40).

The types and amounts of foods and beverages consumed during the previous 24-h period were collected in person using the multi-pass, 24-h dietary interview method. For the 1999–2000 NHANES, the USDA 1994–1998 Survey Nutrient Database was used to code and report intake of energy and nutrients. The USDA Food and Nutrient Database for Dietary Studies version 1.0 (41) was used for processing the dietary interview data for 2001–2002. We used the database released by the USDA to determine vitamin A in μ retinol activity equivalents and vitamin E in mg, alpha-tocopherol for NHANES 1999–2002 (42). Added sugars data were from the MyPyramid Equivalents Database (43).

We combined data from NHANES 1999–2000 and 2001–2002 and used data from participants $\geq$ 4 y with dietary interviews deemed "reliable and met minimum criteria" (total n = 15,537); pregnant and/or lactating women were excluded. First, we calculated HEI scores using programs recently released by the USDA (28). The revised HEI, a 12-component, 100-point score, is a composite measure of overall diet quality based on nutrients and food groups. The food components include total fruit, whole fruit, total vegetables, dark green and orange vegetables and legumes, total grains, whole grains, milk, meat and beans, and oils. The nutrient components include saturated fat, sodium, and energy from solid fat, alcohol, and added sugars. Second, we calculated a composite measure of food nutritional quality for each participant based on NRF indices. All foods consumed by each respondent were first scored using the NRF*n*.3 family of algorithms (Table 1), with percent reference DV capped at 100% DV to avoid overvaluing foods that provide very large amounts of a single nutrient. For each respondent, NRF scores were summed and then divided by the number of reference amounts customarily consumed (RACC) servings or 100-kcal units consumed, thus providing a "weighted average" daily food quality score. In this way, we obtained both daily HEI scores and daily NRF*n*.3 values for each respondent.

Statistical analysis. Regression analyses were conducted using HEI as the dependent variable and the weighted energy average food quality score provided by each NRF*n*.3 algorithm as the independent variable. All models were adjusted for gender, ethnicity, and age. All analyses were weighted using the NHANES examination 4-y sample weights and adjusted for the complex sample design of NHANES. Analyses were performed with the statistical packages SAS and SUDAAN version 9.0 (RTI). We used the percentage of the variation explained (R^2) and the P-value of models to assess validation of various algorithms. P-values $<$ 0.001 were considered significant.

Past approaches used to validate various dietary assessment tools, typically FFQ, were based on simple correlations (44–46). Significant correlations of $\geq$0.5, an R^2 of 0.25, were deemed indicative of a reasonable relationship between FFQ estimates of dietary intake and actual intake (44). The present goal was to evaluate the percent of variance in HEI accounted for to help select the optimal NRF algorithm(s).

Characteristics of NRF9.3 scores for foods. NRF algorithms with the best predictive relationship with HEI were then used to score all foods. We chose to use the algorithm using sums, because this is the simplest calculation and weights all nutrients equally (algorithm of means is actually a form of weighting). Foods consumed within NHANES 1999–2002 were scored via NRF9.3 per RACC (n = 5096) and per 100 kcal (n = 5085, because zero energy foods cannot be scored) and grouped into food groups primarily by the first digit of the USDA coding scheme. However, all mixtures or mixed dishes (e.g. soups, meat and vegetables, etc.) were put into a separate category. To avoid double-counting beans as both a vegetable and a protein source, beans were grouped with vegetables, as previously done by USDA in describing MyPyramid food patterns. Sweets, beverages, fats, and oils (foods

[8] 1 kcal = 4.184 kJ.

TABLE 1 Nutrients to encourage and LIM in selected NRF nutrient profile models[1,2]

NRF models	Macronutrients	Vitamins	Minerals	LIM
LIM				Saturated fat, added sugar, Na
LIMt				Saturated fat, total sugar, Na
NRF6.3	Protein, fiber	A, C	Ca, Fe	Saturated fat, added sugar, Na
NRF9.3	Protein, fiber	A, C, E	Ca, Fe, Mg, K	Saturated fat, added sugar,[3] Na
NRF11.3	Protein, fiber	A, C, E, B-12	Ca, Fe, Mg, Zn, K	Saturated fat, added sugar, Na
NRF15.3	Protein, fiber, monounsaturated fat	A, C, D, E, thiamin, riboflavin, B-12, folate	Ca, Fe, Zn, K	Saturated fat, added sugar, Na

[1] As an example, NRF scores were calculated as the sum of the DV of nutrients to encourage and subtracting the DV for LIM: NRF9.3 = (protein g/50 g + fiber g/25 g + vitamin A IU/5000 IU + vitamin C mg/60 mg + vitamin E IU/30 IU + calcium mg/1000 mg + iron mg/18 mg + magnesium mg/400 mg + potassium mg/3500 mg – saturated fat g/20 g – added sugars g/50 g – sodium mg/2400 mg) × 100.
[2] Indices were calculated per RACC and per 100 kcal.
[3] A nutrient profile model based on NRF9.3 was assessed replacing total sugars for added sugars.

with an 8 or 9 as first digit in USDA coding scheme) were grouped as "other."

Results

Validation. All NRF indices evaluated had a strong relation ($P < 0.001$) with HEI (**Table 2**). The LIM score per 100 kcal and per RACC had an inverse relationship with HEI and the lowest R^2 (0.231 and 0.327 per RACC and per 100 kcal, respectively). All other NRF*n*.3 algorithms were positively correlated ($P < 0.001$) with HEI. NRF6.3 and 9.3 had similar R^2 for per RACC (0.405 and 0.402, respectively). NRF9.3 had the highest R^2 for 100 kcal (0.453). NRF11.3 and 15.3 had slightly lower R^2 values calculated per 100 kcal (0.397 and 0.340, respectively) and per RACC (0.329 and 0.230, respectively).

Replacement of added sugars with total sugars resulted in slightly lower (3–5 units) R^2 for all NRF*n*.3 algorithms per RACC (**Fig. 1***A*) and per 100 kcal (Fig. 1*B*). That said, NRF9.3 with inclusion of total sugars in place of added sugars still explained >35% of variation in HEI. To evaluate the impact of various calculation methods, we used NRF9.3 and calculated indices based on sums, means, and ratios (**Fig. 2**). Whereas the R^2 of regression models with algorithms based on sums and means were similar, the NRF9.3 based on ratios R^2 was dramatically lower on per 100 kcal bases (0.454, 0.465, and 0.071, respectively) or per RACC (0.402, 0.420, and 0.085, respectively).

NRF9.3 food score characteristics. Because NRF9.3 per 100 kcal and per RACC had the best ability to predict HEI, we then scored all foods with these algorithms and examined scores within defined food groups. In every food group, there were very high (<100) and very low (<0) scores based on either 100 kcal (**Fig. 3***A*) or per RACC (Fig. 3*B*). Compared with other food groups, fruits and vegetables had the highest median food score

TABLE 2 Mean LIM and NRF*n*.3 values based on sums in NHANES, 1999–2002, of those age ≥4 y by gender and linear regressions of LIM and NRF*n*.3 models on HEI[1,2]

Based on sums	All, *n* = 15,537	Male, *n* = 7832	Female, *n* = 7705	Linear regression on HEI: β-Coefficient	*P*-value	R^2
Per 100 kcal[3]						
LIM[4]	21.5 ± 0.2	21.5 ± 0.2	21.6 ± 0.2	−1.26 ± 0.03	<0.001	0.327
NRF6.3[5]	5.0 ± 0.4	4.1 ± 0.4	5.8 ± 0.5	0.66 ± 0.02	<0.001	0.434
NRF9.3[6]	13.3 ± 0.5	12.2 ± 0.4	14.4 ± 0.5	0.58 ± 0.02	<0.001	0.453
NRF11.3[7]	21.1 ± 0.5	20.1 ± 0.5	22.1 ± 0.6	0.46 ± 0.02	<0.001	0.397
NRF15.3[8]	41.5 ± 0.6	40.2 ± 0.6	42.9 ± 0.7	0.32 ± 0.01	<0.001	0.340
Per RACC						
LIM[4]	24.5 ± 0.2	25.1 ± 0.2	23.9 ± 0.3	−0.58 ± 0.02	<0.001	0.231
NRF6.3[5]	5.3 ± 0.4	4.6 ± 0.4	6.1 ± 0.5	0.57 ± 0.01	<0.001	0.404
NRF9.3[6]	14.4 ± 0.5	13.6 ± 0.5	15.1 ± 0.5	0.49 ± 0.01	<0.001	0.402
NRF11.3[7]	23.1 ± 0.5	22.7 ± 0.5	23.3 ± 0.6	0.36 ± 0.01	<0.001	0.328
NRF15.3[8]	46.4 ± 0.6	46.4 ± 0.6	46.2 ± 0.7	0.20 ± 0.01	<0.001	0.229

[1] Values are sample-weighted mean ± SE (estimated by linearization method of SUDAAN).
[2] Data are from NHANES, 1999–2002, age ≥4 y, excluding pregnant/lactating females, *n* = 15,537.
[3] 1 kcal = 4.18 kJ.
[4] The 3 nutrients were saturated fat, sodium, and added sugar.
[5] The 6 nutrients were protein, vitamin A, vitamin C, calcium, iron, and fiber.
[6] The 9 nutrients were protein, vitamin A, vitamin E, vitamin C, calcium, magnesium, iron, fiber, and potassium.
[7] The 11 nutrients were protein, vitamin A, vitamin E, vitamin C, vitamin B-12, calcium, magnesium, iron, zinc, fiber, and potassium.
[8] The 15 nutrients were protein, vitamin A, vitamin E, vitamin C, thiamin, riboflavin, folate, vitamin B-12, calcium, iron, zinc, fiber, monounsaturated fat, potassium, and vitamin D.

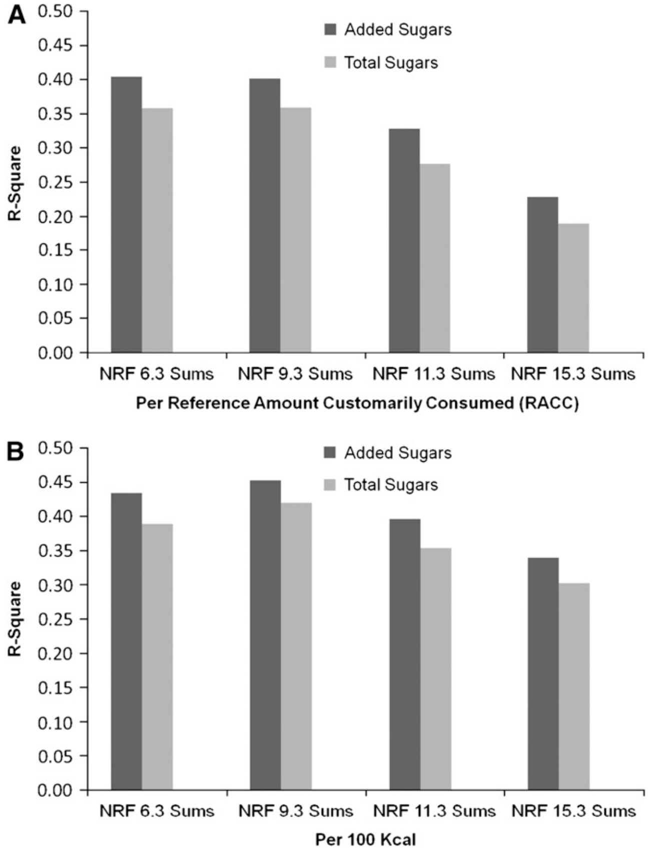

FIGURE 1 R^2 comparison of NRF*n*.3 algorithms calculated with added sugars or total sugars per RACC (*A*) and per 100 kcal (*B*) from regression models predicting HEI. NRF6.3 is the sum of the DV for protein, dietary fiber, vitamin A, vitamin C, calcium, and iron minus the DV of saturated fat, added sugars, and sodium; NRF9.3 is NRF6.3 plus DV for vitamin E, magnesium, and potassium; NRF11.3 is NRF9.3 plus DV for vitamin B-12 and zinc; and NRF15.3 is NRF6.3 plus DV for monounsaturated fats, vitamin D, vitamin E, thiamin, riboflavin, vitamin B-12, folate, magnesium, zinc, and potassium. Regression analyses for all NRF*n*.3 algorithms with HEI adjusted for age, gender, and ethnicity were significant, $P < 0.0001$.

based on NRF9.3 per 100 kcal (**Fig. 4***A*) or per RACC (Fig. 4*B*). Scores based on RACC lowered median values for fruits and vegetables and increased median values for meat and mixture food groups. Scores for selected foods are presented in **Supplemental Table 1**.

Discussion

Diet scores based on a family of NRF indices were significantly related to HEI. The algorithms that best predicted HEI included both nutrients to encourage and LIM on both a 100 kcal and per RACC basis. These results confirmed that better diets do not necessarily come from just restricting certain nutrients; the addition of beneficial nutrients is critical for a higher diet quality.

There were lower, but acceptable, correlations (>0.5) of HEI when total sugars replaced added sugars as one of the LIM. The lower results were probably due to naturally occurring sugars in fruits and some dairy products. Because added sugars data are less readily available, including total sugars as a nutrient to limit (with a concomitant higher DV than for added sugars) may be a reasonable option. Additionally, because algorithms with added sugars performed better, providing this information on food labels, as has been recommended, should be considered.

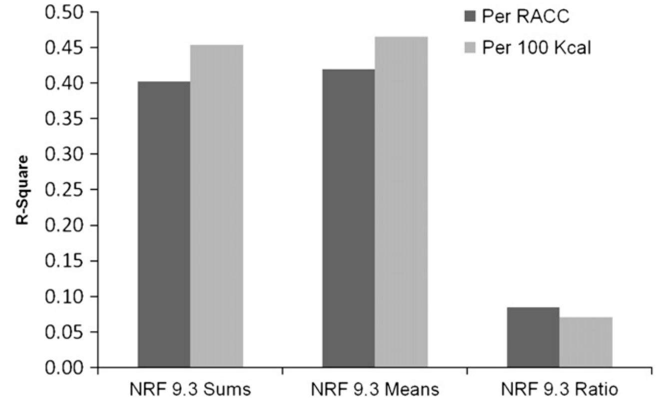

FIGURE 2 R^2 comparison of NRF9.3 algorithms calculated as sums, means, or as a ratio from regression models predicting HEI. NRF9.3 is the sum of the DV for protein, dietary fiber, vitamin A, vitamin C, vitamin E, calcium, magnesium, iron, and potassium minus the DV of saturated fat, added sugars, and sodium. Regression analyses for all calculation methods of NRF9.3 algorithms with HEI adjusted for age, gender, and ethnicity were significant, $P < 0.0001$.

The present results confirm previous efforts (30) showing that increases in the number of nutrients above 9–10 provided little additional benefit in predicting overall diet quality and in the present study actually reduced the amount of variation explained

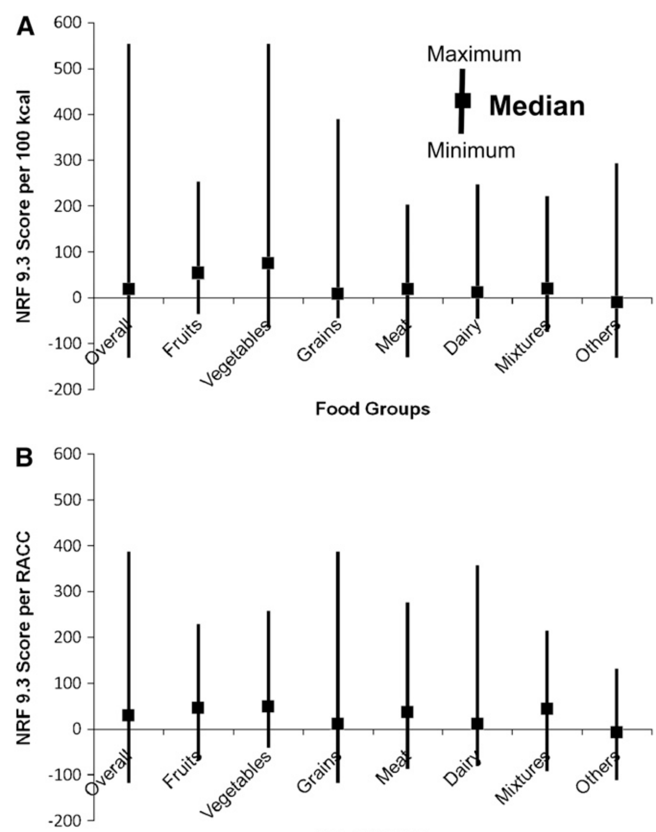

FIGURE 3 Median and range of food scores by food group for NRF9.3 per RACC (*A*) and per 100 kcal (*B*). NRF9.3 is the sum of the DV for protein, dietary fiber, vitamin A, vitamin C, vitamin E, calcium, magnesium, iron, and potassium minus the DV of saturated fat, added sugars, and sodium. 1 kcal = 4.18 kJ.

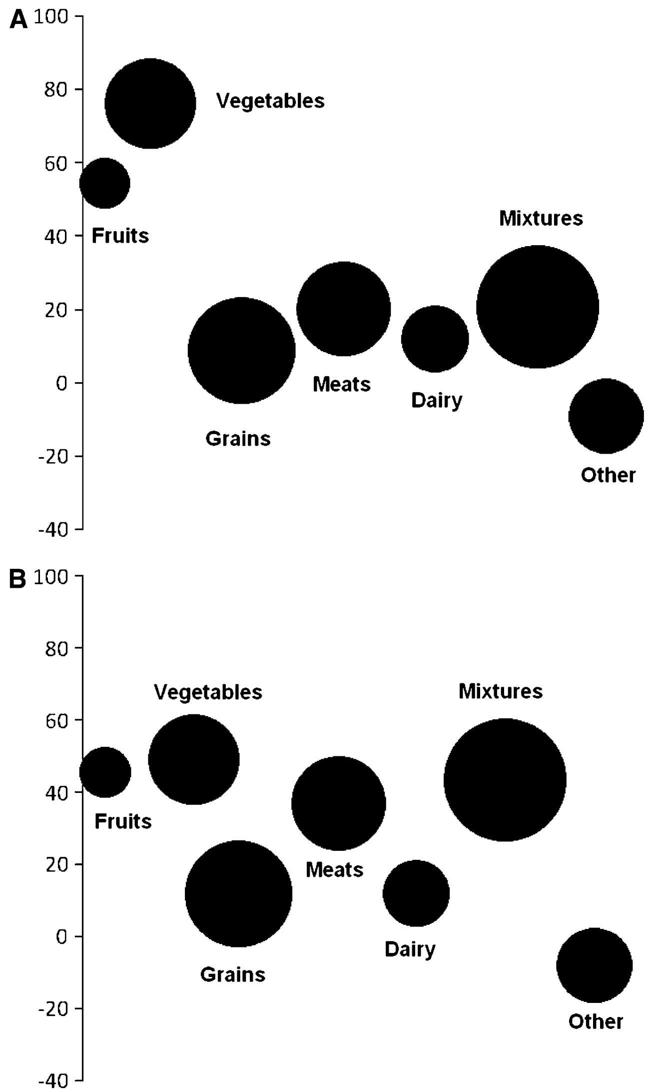

FIGURE 4 Number of foods and median of food scores by food group for NRF9.3 per RACC (*A*) and per 100 kcal (*B*). Circle is located at the median; size of circle represents number of food items in that food group. NRF9.3 is the sum of the DV for protein, dietary fiber, vitamin A, vitamin C, vitamin E, calcium, magnesium, iron, and potassium minus the DV of saturated fat, added sugars, and sodium. 1 kcal = 4.18 kJ.

in diet quality. Regarding reference bases, both approaches (100 kcal or RACC) had similar results when examining various NRF*n*.3 algorithms and predicting HEI. Algorithms per 100 kcal had slightly higher R^2 values than those based on RACC. Whether the differences in R^2 are real or a function of the process used to develop RACC (developed by FDA using intake data from the 1980s) remains to be determined. In the US, RACC are well established and, thus, algorithms using this basis may be preferred to link to current food labeling efforts. Outside the US, RACC do not currently exist. For these areas, RACC could be developed or nutrient profiling could be performed per 100 kcal.

Compared with algorithms based on sums or means, those based on ratios appear to have inherent problems explaining variation in HEI. Given that higher ratio scores can be obtained by either increasing the numerator or decreasing the denominator, it seems ratio scores will have to be radically transformed before they will be useful for consumers. Instances of weighted nutrient density scores (15,47) 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. Weighting has also been based on expert opinion on the importance of each nutrient in the population diet. But in the final analysis, a priori weighting of algorithms is essentially arbitrary and judicious selection of nutrients based on the best available science is a better alternative. In the present study, NRF algorithms were not weighted.

NRF9.3 sum scores per 100 kcal and per RACC were capable of distinguishing nutritional benefits within a food group (30) (Supplemental Table 1). Whole-grain products scored higher than non-whole–grain versions, fruits with less added sugar scored higher than those with more added sugar, and 100% fruit products scored higher than other soft drink choices. Lower fat dairy products and leaner protein sources clearly had higher scores than higher fat counterparts (Supplemental Table 1). Although these scores could be used to assess food nutritional quality, further research should examine whether standardizing scores across/within food groups would allow the development of even more useful tools to help consumers select the most nutrient-dense choices within a food group and, ultimately, a healthier diet. After such standardization, it may be helpful to consumers to separate scores in distinct groups (tertiles, quartiles, or quintiles) rather than using a scoring system ranging from large negative to large positive values (−131 to 555 with NRF9.3 per 100 kcal). Ultimately, consumer research will have to determine the best approach to use.

Our analyses demonstrate that NRF9.3 based on 100 kcal and on RACC explained the most variation in HEI and can serve as a benchmark for future algorithm development. Other nutrient profiling efforts should also conduct validation analyses similar to those presented to ensure that the approach used is related to an objective measure of diet quality. Considerable research is still necessary to determine how to best present nutrient profiling to consumers in a way that will actually lead to selection of foods that improve the overall diet.

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