Proceedings of the Nutrition Society (2017), **76**, 220–229 doi:10.1017/S0029665117000416
 First published online 9 June 2017

Nutrition Society Summer Meeting 2016 held at University College Dublin on 11–14 July 2016

Conference on 'New technology in nutrition research and practice' Nutrient profiling as a tool to respond to public health needs

Uses of nutrient profiling to address public health needs: from regulation to reformulation

Adam Drewnowski
Center for Public Health Nutrition, University of Washington, Seattle, WA, USA

Nutrient profiling (NP) models rate the nutritional quality of individual foods, based on their nutrient composition. Their goal is to identify nutrient-rich foods, generally defined as those that contain more nutrients than calories and are low in fat, sugar and salt. NP models have provided the scientific basis for evaluating nutrition and health claims and regulating marketing and advertising to children. The food industry has used NP methods to reformulate product portfolios. To help define what we mean by healthy foods, NP models need to be based on published nutrition standards, mandated serving sizes and open-source nutrient composition databases. Specifically, the development and testing of NP models for public health should follow the seven decision steps outlined by the European Food Safety Authority. Consistent with this scheme, the nutrient-rich food (NRF) family of indices was based on a variable number of qualifying nutrients (from six to fifteen) and on three disqualifying nutrients (saturated fat, added sugar, sodium). The selection of nutrients and daily reference amounts followed nutrient standards for the USA. The base of calculation was 418·4 kJ (100 kcal), in preference to 100 g, or serving sizes. The NRF algorithms, based on unweighted sums of percent daily values, subtracted negative (LIM) from positive (NR*n*) subscores (NR*n* – LIM). NRF model performance was tested with respect to energy density and independent measures of a healthy diet. Whereas past uses of NP modelling have been regulatory or educational, voluntary product reformulation by the food industry may have most impact on public health.

Nutrient profiling: Nutrient-rich foods: Nutrient-rich food index: Nutriscore

Intended to capture the nutritional quality of foods, nutrient profiling (NP) models have found a wide variety of public health uses, both educational and regulatory[1,2]. Their initial development was spurred by the European Union requirement that nutrition and health claims be evaluated based on the foods' nutrient content[3]. Since then, NP models have provided the scientific basis for conveying nutrition information to the public in the form of front-of-pack logos, supermarket shelf labels or through portable apps[4]. NP models have guided the regulation of marketing and advertising to children, both in the European Union and elsewhere[5–7]. Four alternative front-of-pack food labelling systems are currently being tested in France[8]. In a number of countries, energy and nutrient density of selected beverages and foods have been used to set standards for warning labels and for taxation purposes[9]. The principal aim of the diverse NP approaches has been to help consumers identify nutrient-rich foods (NRF), shape food purchase decisions and improve diet quality[10].

Through voluntary action, the food industry has also used NP methods to review nutrient quality of product portfolios[11,12]. Here, the focus has been on improving nutrient composition of processed foods by reducing the foods' content of saturated fat, added sugar and salt[11,12]. The goal of industry measures was to ensure

Abbreviations: FDA, Food and Drug Administration; FNDDS, Food and Nutrient Database for Dietary Studies; NP, nutrient profiling; NRF, nutrient-rich food; RACC, reference amounts customarily consumed.
Corresponding author: A. Drewnowski, fax (206) 685-1696, email adamdrew@u.washington.edu

that the product portfolios meet internal nutrition standards[13].

In the USA, the Food and Drug Administration (FDA) has only recently started a public process to redefine the claim of 'healthy' for food labelling[14]. The key question, for which comments were requested by the FDA, is whether the term 'healthy' as applied to single foods, should be based on the foods' nutrient content, or were some foods intrinsically healthy, regardless of their nutrient composition? If so, then which food groups, if any, would qualify? Conversely, if the term 'healthy' were to be based on nutrient content alone, which would be the qualifying and the disqualifying nutrients? Should qualifying nutrients be those whose recommended intakes are not met by a given population (i.e. 'shortfall' nutrients), or should the list be expanded to include those nutrients that contribute to overall health? Finally, should fortification be taken into account, or should the term 'healthy' be reserved for foods that are naturally nutrient-rich?[14].

Many of the questions, presently asked by the US FDA, have already been asked and answered in prior NP research[15–17]. Most existing NP models define foods as healthy, nutritious, or nutrient-rich based on their nutrient content per reference amount, variously defined in terms of energy, weight or serving size. These quantitative metrics of nutrient density can be applied to individual foods, composite meals, or to total diets[15,18]. NP of meals and diets has also taken nutrient balance and nutrient cost into account[19].

Using NP models to capture the nutritional quality of foods poses a number of challenges[7,8,15,18]. Multiple decisions need to be made that concern the type of NP model, the selection of qualifying and disqualifying nutrients, the selection of reference standards, and the basis of calculation: 418·4 kJ (100 kcal), 100 g, or serving size[17,20]. Alternative NP algorithms need to be generated and tested. The final agreed-upon NP model needs to be validated[21–25]. The seven major steps in developng NP models for public health have been outlined by the European Food Safety Authority and are described below.

The development of the NRF family of scores will serve as an example of the complex process. Developed in parallel with the French SAIN,LIM system[26], the NRF NP models have now been tested and validated in a number of countries, including France[27], the Netherlands[28,29], Australia[30] and China[31].

Seven steps to nutrient profiling

The creation of the NRF family of NP models followed the pathway outlined by the European Food Safety Authority[17,20]. The critical steps in the development of NP models are summarised in Fig. 1. The NRF models were developed and tested using the open-access Food and Nutrient Database for Dietary Studies (FNDDS) available from the US Department of Agriculture[32]. The FNDDS provides energy and nutrient content for sixty nutrients, expressed per 100 g food, edible portion, for 6940 foods from all food groups, including some brand name items. Additional data for added sugar and vitamin D were obtained from the US Department of Agriculture[33]. Common food portions provided in the FNDDS were replaced with the so-called reference amounts customarily consumed (RACC). Food labelling in the USA is based on RACC serving sizes mandated by the FDA[34]. A large branded food products database has recently become available, the result of a collaboration between the US Department of Agriculture and the International Lifes Sciences Instiute North America[35].

Category-specific or across the board?

NP models can be across-the-board or category specific. In across-the-board NP models, the same nutrients and the same nutrient standards are applied to all foods and beverages in the database. Category-specific models allow for certain adjustment of nutrient standards by food group. The category-specific approach recognises that while most nutrients are provided by multiple food groups, for some nutrients there is one food group that is the predominant source.

For example, analyses of the percent contribution of different food groups to selected qualifying nutrient totals in the US Department of Agriculture food patterns[36] showed that milk and dairy products supplied 67 % of dietary calcium and 64 % of vitamin D. Vegetables and fruit supplied fibre (54 %) and potassium (53 %). Dairy was the major source of vitamin A (32 %) whereas vegetables were the main source of provitamin A carotenoids (34 %). Polyunsaturated fats were provided by fats and oils (68 %). On the debit side, sweetened beverages were the major single source of added sugars (about one third of total) in the US diet, whereas pizza was the major source of sodium among teenagers and young adults. Those food groups are potential targets for reformulation[11,12].

Category-specific NP models can match selected nutrients to the most appropriate food groups or product categories to select the best in class. There are limits to reformulation, however. Standards of identity, food science issues and safety concerns do not permit for easy removal of cocoa butter or sugar from chocolate or sodium from milk or cheese.

Among the established NP models, the NRF and SAIN,LIM models were both across-the-board models. By contrast the Unilevel Choices model was from the beginning category-specific[37], as is the Nestlé NP system[38]. The current view is that category-specific models are more useful for the reformulation of processed foods, providing more detailed benchmarks and measures of success. One approach to more efficient product reformulation has been to align NP categories with product lines.

Selection of qualifying and disqualifying nutrients

The second step concerns the selection of qualifying and disqualifying nutrients. Aligned with public health goals, these have also been called nutrients to encourage and nutrients to limit[39], respectively. An alternative

https://doi.org/10.1017/S0029665117000416 Published online by Cambridge University Press

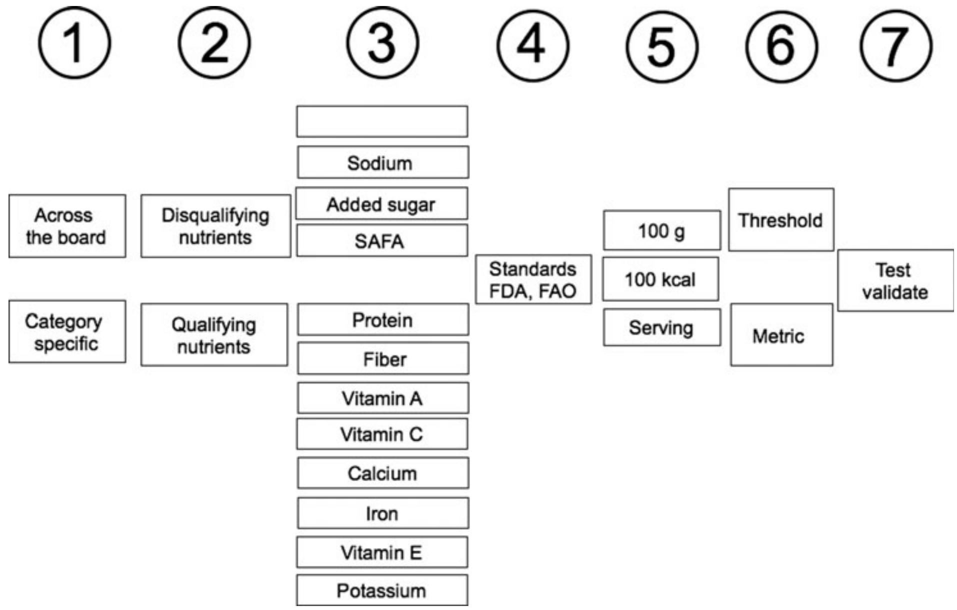

Fig. 1. Scheme to illustrate decision points in the development of the NRF9.3 nutrient profiling model. SAFA, saturated fatty acids; FDA, the Food and Drug Administration; FAO, the Food and Drug Organization.

terminology, based on population consumption patterns, has referred to shortfall nutrients and to nutrients of public health concern. Whereas shortfall nutrients are those that are not consumed by the population in recommended amounts, nutrients of public health concern, notably saturated fat, added sugar and salt, are consumed to excess[39].

The selection of qualifying and disqualifying nutrients needs to be responsive to specific population health needs, especially in the low and middle income countries. Patterns of nutrient deficiency vary by geography, socio-economic status and culture-dependent food habits[40]. Whereas high-quality animal protein, heme iron and bio-available calcium are readily available in the USA, that may not be the case elsewhere.

The selection of index nutrients to include in the NRF family of NutriScores was based on the regulatory environment. The US FDA has established standards that can disqualify food products from carrying a nutrition or health claim[34]. Foods are permitted to be called healthy, depending on their content of protein, fibre, vitamins A and C, calcium and iron. Potassium and vitamin D were recently added to the list. Foods are disqualified from nutrition and health claims if they contain above-specified amounts of total fat, saturated fat, *trans*-fat, cholesterol and sodium. As noted earlier, the FDA is revisiting this issue in 2017[41].

The Nutrition Labeling and Education Act[42] requires that food labels in the USA list total energies, energies from fat and amounts of total fat, saturated fat, cholesterol, sodium, total carbohydrate, dietary fibre, sugars, protein, vitamins A and C, calcium and iron. Listing energies from poly- and monounsaturated fats or additional vitamins and minerals is voluntary, unless there is a nutrition or health claim. A recent FDA initiative was to replace total sugar on the Nutrition Facts Panel with added sugar[43].

The Dietary Guidelines for Americans[44] have identified fibre, vitamins A, C, and E, calcium, potassium and magnesium as shortfall nutrients. More recent dietary concerns have addressed inadequate consumption of fibre, potassium, calcium and vitamin D.

The many combinations of qualifying and disqualifying nutrients that were used in the development of the NRF family of scores are summarised in Table 1[17,18,20]. The NR (NR*n*) subscores were based on a variable number *n* of qualifying nutrients. The qualifying nutrients have generally included protein, fibre and a variety of vitamins, minerals, trace elements and other dietary ingredients. The NR6 model was based on the six nutrients that the FDA uses to define healthy foods. The NR9 model was based on the 6 FDA nutrients and vitamin E, magnesium, and potassium. The NR11 model was based on the 6 FDA nutrients and an additional five nutrients of concern (vitamin E, magnesium, potassium, vitamin B_{12} and zinc). The NR15 model was the original Naturally NR (NNR) score based on protein, fibre, vitamins A, C, D, E, B_1, B_2 and B_{12}, folate, calcium, iron, potassium and zinc[18].

It bears emphasising that NP models with more qualifying nutrients did not perform better than models where the number of qualifying nutrients was deliberatley kept low. Although a model based on twenty-three qualifying nutrients might seem more comprehensive, many nutrients are highly correlated with each other. For example, fibre, vitamin C, folate, vitamin A (as carotenoids), potassium and magnesium are all, to differing extents, associated with vegetables and fruit. A model featuring all of these nutrients would favour vegetables and fruit

Table 1. The selection qualifying and disqualifying nutrients in the nutrient-rich foods family of scores and in related nutrient profiling (NP) models

NP model	Macronutrients	Vitamins	Minerals	Reference
NR5	Protein, fibre	C	Ca, Fe	Drewnowski *et al.*[17]
NR6	Protein, fibre	A, C	Ca, Fe	Drewnowski & Fulgoni[15]
NR9	Protein, fibre	A, C, E	Ca, Fe, Mg, K	Drewnowski & Fulgoni[15]
NR9z	Protein, fibre	A, C, E	Ca, Fe, Zn, K	Drewnowski & Fulgoni[15]
NR11	Protein, fibrer	A, C, E, B_{12}	Ca, Fe, Zn, Mg, K	Drewnowski & Fulgoni[15]
NR12	Protein, fibre	A, C, E, thiamin, riboflavin, B_{12}	Ca, Fe, Zn, K	Drewnowski & Fulgoni[15]
NR14	Protein, fibre	C, D, E, thiamin, riboflavin, B_{12}, folate	Ca, Fe, Zn, K	Drewnowski & Fulgoni[15]
NNR15	Protein, fibre, MUFA	C, D, E, thiamin, riboflavin, B_{12}, folate	Ca, Fe, Zn, K	Drewnowski[18]
NDS16 afssa	Protein, fibre, linolenic, DHA	C, D, E, thiamin, riboflavin, B_6, folate	Ca, Fe, Zn, Mg, K	Drewnowski *et al.*[17]
NDS23	Protein, fibre, linoleic, linolenic, DHA	A, C, D, E, thiamin, riboflavin, B_6, B_{12}, niacin, folate	Ca, Fe, Zn, Mg, Cu, Se, K, I, Na	Maillot *et al.*[21]
LIM	Saturated fat, added sugar			

to the exclusion of most other foods. As noted later, model performance was similar whether the number of qualifying nutrients was six or fifteen. Including sixteen, twenty-three or even more nutrients did not add substantially to the NP models' performance.

The disqualifying nutrients have typically included total fat, saturated fat, sugar (total or added) and sodium[15]. Some NP models have included total fat, saturated fat, cholesterol and sodium[18], whereas others also used *trans*-fats and sugars. Also included at times were energy and total sugars. The French LIM index, a subcomponent of the SAIN,LIM score was based on saturated fat, added sugar and sodium[17,20]. The common disqualifying component of the NRF family of scores was based on the same three nutrients: saturated fat, added sugar and sodium. Depending on data availability and current trends, alternative versions of LIM have used total sugar, added sugar and 'free sugar', the latter including sugar in 100 % fruit juices and honey[27].

Selection of nutrient standards

The third step concerns the selection of nutrient standards for use in NP models. Nutrient standards are typically based on local reference dietary amounts, defaulting to values published by the Food and Agriculture Organization when local dietary standards are not available. Nutrition standards were based on the US Reference Daily Values[45,46], used on nutrition labels and published by the FDA. Maximum recommended values for disqualifying nutrients were 20 g for saturated fat, 125 g for total sugar, 50 g for added sugar and 2400 mg for sodium, all based on a 8368 kJ (2000 kcal)/d diet[17,20].

The NRF approach was to convert nutrient amounts per 418·4 kJ (100 kcal) of food to percent daily values (%) per 418·4 kJ (100 kcal). Percent daily values were capped at 100 %, so that foods containing very large amounts of a single nutrient would not have a disproportionately high index score[15].

Compensatory models or not?

The fourth important decision is whether the NP model should be compensatory or not. Existing NP models have been based on qualifying nutrients only, on disqualifying nutrients only, or on some combination of both[1,15,18]. The question is whether the presence of protein, fibre and other qualifying nutrients can compensate for earlier-specified amounts of energies, fat, sugar or salt. Here, some NP systems take the compensatory approach (e.g. the NRF family of scores), whereas others do not (e.g. Nestlé NP system). The SAIN,LIM system finesses the issue by assigning foods into four independent classes based on their qualifying (SAIN) and disqualifying scores (LIM). The current thinking is that a non-compensatory system may be better suited to the reformulation of food products, if only to prevent e.g. vitamin fortification from compensating for excessive amounts of added sugar or fat.

Basis of calculation: 100 g, 418·4 kJ (100 kcal), or serving size?

The fifth set of decisions regards the basis of calculation. NP scores have been calculated based on different reference amounts: per 100 g, per 418·4 kJ (100 kcal) or per food serving. The FDA Nutrition Facts Panel provides nutritional data per serving; no government-mandated serving sizes are used in the European Union. Whereas the British FSA-Ofcom score was based on 100 g, the French SAIN,LIM system used 418·4 kJ (100 kcal) to calculate SAIN and 100 g to calculate LIM. The NRF family of scores was based on 418·4 kJ (100 kcal), with additional analyses conducted per RACC.

NR*n* and LIM scores were calculated per 418·4 kJ (100 kcal), per 100 g and per RACC. In the US, per cent daily values for nutrients listed in the Nutrition Facts Panel are calculated per serving size. Using RACC values has the advantage of linking nutrient profiles to nutrient values as they appear on food labels. RACC values 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), or milk, juices and other beverages (240 g). The FDA has used 139 different RACC values, with some updates made available recently. In general, energy density and RACC values are inversely linked. No government-approved serving

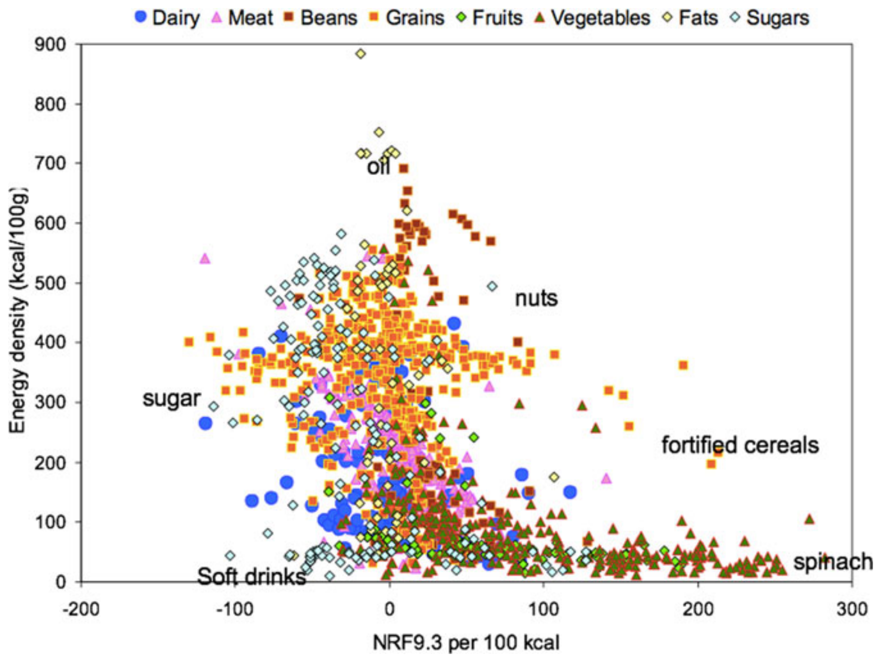

Fig. 2. (Color online) The relation between NRF9.3 scores by food group and energy density of foods (kJ/100 g). Data are for 1387 foods from the USDA Food and Nutrient Database for Dietary Studies.

sizes exist in the European Union at this time; therefore, nutrition information is most often calculated per 100 g.

The nutrient profiling algorithm

The sixth step requires a decision on the NP algorithm. Scores can be threshold based or continuous; the NRF was an example of a continuous score, whereas the FSA-Ofcom was threshold-based. The final score can be based on sums, means or ratios of nutrient content per reference amount. The final agreed-upon NRF algorithm was based on the unweighted sum of capped percent daily values for the nine qualifying nutrients (NR9) and the sum of capped percent maximum recommended values for the three disqualifying nutrients (LIM). The composite NRFn.3 scores were then calculated by subtracting LIM from NR*n* scores, both expressed per 418·4 kJ (100 kcal). The decision was to use the sum rather than the mean, in distinction to SAIN,LIM. NRF algorithms based on subtraction (NR*n* – LIM) yielded a better distribution of values than did those based on ratios (NR*n*:LIM). The final product was described as NRF9.3.

Testing and validation

The seventh and final step requires the validation of the NP model[21–25]. Validation of the NRF index was based on comparing energy-weighted alternative NRF scores to independently obtained measures of a healthy diet. Both NRF scores and diet quality measures were calculated using the large and nationally representative US database, the National Health and Nutrition Examination Survey. Diet quality was established using the Healthy Eating Index, a measure of compliance with the US dietary guidelines. Regression analyses tracked the strength of the association between NRF scores and Healthy Eating Index values for the same participants, showing that optimal results were realised with the NRF9 3 variant of the NRF family of scores. Food rankings generated by NP models have also been compared with expert or professional opinion[47]. Other validation approaches have used the distribution of scores across food groups, or used linear programming to optimise diets based on nutrient density[21].

The continuum of nutrient density

Figure 2 shows the distribution of nutrient density scores within and across different food groups. The FNDDS food groups were milk and milk products; meat, poultry and fish; eggs; legumes, nuts and seeds; grain products; fruit; vegetables; fats and oils; sugars, sweets and beverages. NP analyses were restricted to those foods that were consumed at least once on the 1999–2002 National Health and Nutrition Examination Survey. Since many of the foods in the FNDDS database were never consumed, initial analyses were limited to 5096 foods that appeared in the National Health and Nutrition Examination Survey 24 h recalls. Subsequent analyses imposed a further frequency constraint to ensure that a food appeared at least five times. The resulting database of foods and beverages, profiled using the NRF9.3 method, included fortified products, cooked and prepared foods, and a variety of fresh, canned and frozen foods.

https://doi.org/10.1017/S0029665117000416 Published online by Cambridge University Press

Table 2. Scores for selected foods using NRF9.3/418.4 kJ (100 kcal) and per reference amounts customarily consumed (RACC)

Food code	Food description	NRF9.3/418·4 kJ (100 kcal)	NRF9.3/RACC	Frequency NHANES
11111000	Milk, cow's, whole	26·1	38·2	6609
11112110	Milk, cow's, 2 % fat	43·3	52·8	4715
11112210	Milk, cow's, 1 % fat	59·0	60·4	1326
11113000	Milk, cow's, skim	83·5	69·6	1759
11411100	Yoghurt, plain, whole milk	28·3	38·9	7
11411200	Yoghurt, plain, lowfat milk	55·0	78·0	24
11411300	Yoghurt, plain, nonfat milk	74·5	93·9	34
14109010	Cheese, Swiss	17·2	19·6	332
13110100	Ice cream, regular	−15·7	−20·8	1166
21101130	Beef steak, broiled, lean	33·4	53·1	583
24122120	Chicken, breast, roasted, w/o skin	38·7	54·0	318
24201020	Turkey, breast, cooked, w/o skin	45·2	60·0	31
26137120	Salmon, baked or broiled	36·0	52·4	89
26319130	Shrimp, steamed or boiled	57·0	66·9	106
25210210	Frankfurter or hot dog, beef	−19·3	−36·2	476
31103000	Egg, whole, boiled	20·3	15·6	342
42100100	Almonds, NFS	53·4	92·6	45
42111000	Peanuts, NFS	25·4	45·7	103
57101000	All-Bran cereal RTE	156·6	223·9	23
57123000	Cheerios	78·7	87·2	602
51101000	Bread, white	11·3	15·0	3357
53104500	Cheesecake	−14·5	−58·2	89
63223020	Strawberries, raw	375·9	168·4	486
63109010	Cantaloupe (muskmelon), raw	263·9	125·6	536
61119010	Orange, raw	242·4	159·5	932
61210220	Orange juice, 100 %	170·8	178·6	3011
63101000	Apple, raw	46·7	34·0	1910
75122100	Pepper, sweet, green, raw	607·7	103·3	232
72201100	Broccoli, raw	422·0	122·0	205
73101010	Carrots, raw	234·9	81·9	1265
74101000	Tomatoes, raw	248·9	38·1	3,612
82104000	Olive oil	0·7	0·8	120
91700010	Candy, NFS	−25·9	−39·8	27
92410310	Soft drink, cola-type	−55·8	−50·8	5637
92510610	Fruit drink	−35·6	−42·4	1032

NHANES, National Health and Nutrition Examination Survey; w/o, without; RTE, ready to eat; NFS, not further specified.

The NRF9.3 nutrient density scores fell along a continuum that ranged roughly from sugar to spinach. Foods with high content of qualifying index nutrients had higher NRF scores, whereas foods with high content of saturated fat, added sugars and sodium did not. As expected, vegetables and fruit scored higher than did grains, fats and sweets.

The NRF9.3 score distinguished nutrient density not only across but also within food groups. For example, dairy products were aligned from left to right based on their saturated fat content. Skim milk and low-fat yoghurt scored higher than did ice cream or full-fat cheese. Vegetables ranged from starchy to low-energy-density salad greens. Fruit was separated based on energy density and added sugar content. Fortified cereals, nuts, beans and legumes had high nutrient density scores, despite being energy-dense foods. Otherwise, there was a general inverse association between energy content and nutrient density of foods, understandable given that nutrient density was expressed as nutrients per energy.

The corresponding NRF scores for selected foods, calculated per 418·4 kJ (100 kcal) and per RACC are shown in Table 2. Of note is the finding that low-energy-density vegetables and fruit has very high NRF scores expressed per 418·4 kJ (100 kcal). The scores were reduced when nutrient density was recalculated per RACC.

Comparisons with energy density and cost

Energy density is driven by the water content of foods. For the most part, foods that are energy-dense are foods that are dry. A strong association between an NP model and energy density would indicate that the model penalises dry foods, favouring instead foods with a high water content. A very strong association would mean that the NP model simply tracks energy density of foods, rather than their nutritional value.

Relating the generated scores to energy density provided a crude first test of NRF index performance[17,20]. In general, NP models based on 100 g reference amounts were closely linked to energy density of foods (kJ/100 g). The Food Standards Agency (FSA)-Ofcom model, in particular, captured the foods enegy density but provided

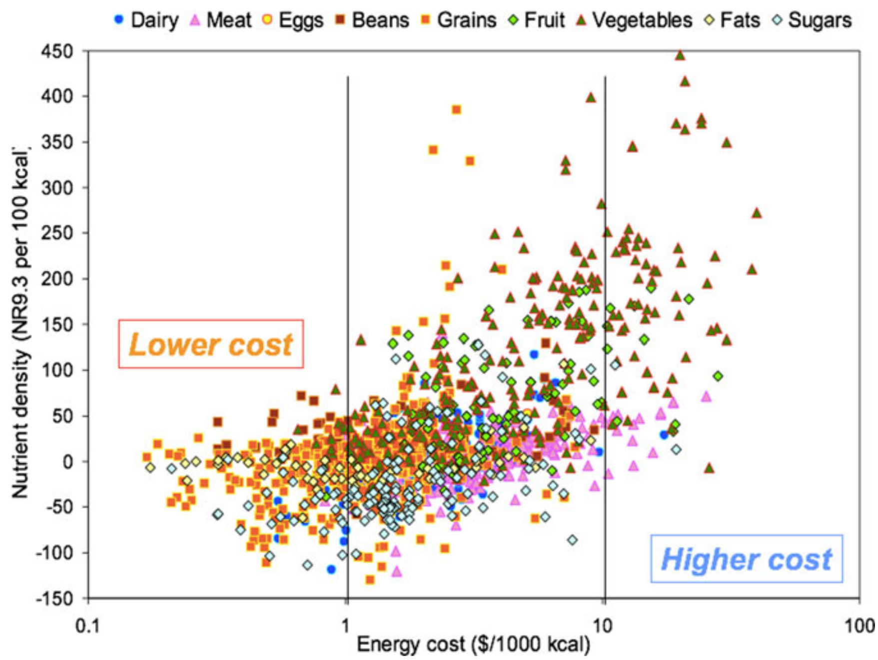

Fig. 3. (Color online) The relation between NRF9.3 scores by food group and energy cost of foods ($/4184 kJ (1000 kcal)). Data are for 1387 foods from USDA Food and Nutrient Database for Dietary Studies.

little information otherwise[15]. In preliminary tests, the FSA-Ofcom score was no different from the LIM subscore, used in the NRF and the SAIN,LIM models. LIM subscores calculated per 100 g strongly penalised foods with saturated fat and sodium that were consumed in serving sizes well below 100 g (e.g. cheese). LIM per RACC penalised sugary beverages that were consumed in 246 g portion sizes[15].

NP models based on 100 g cannot accommodate the wide variation in serving sizes across food groups and tend to penalise energy-dense foods consumed in small quantities (nuts, dried fruit, cheese) and give overly favourable scores to beverages. A system based on 100 g can be very lenient toward sugary beverages unless special provisions are made. To correct for discrepancies in volume, the British FSA-Ofcom score multiplies the negative subscore for beverages by a factor of 2[47].

Changing the base of calculation (100 g or 418·4 kJ (100 kcal)) can produce very different NRF scores. The per 418·4 kJ (100 kcal) score benefited very-low-energy-density vegetables and salad greens, such as spinach, lettuce, endive, water cress and cabbage. By contrast, the per 100 g score was more favourable to energy-dense foods, notably nuts and seeds, protein powder and fortified cereals.

Scores based on serving sizes benefited foods that were consumed in amounts >100 g. That group included fruit and fruit juices, cooked vegetables and juices, milk and yoghurts, and other beverages and mixed foods. Conversely, foods eaten in amounts <100 g, such as nuts and seeds and fortified cereals, had lower RACC-based scores.

NP models have also served as a starting point for studies on the economics of food choice behaviour. In studies on affordability metrics, a food prices vector was added to the standard nutrient composition database to calculate energies and nutrients per penny[48]. The concern was that healthy foods, as identified using the NP approach, would invariably turn out to be more expensive, at least on a per energy basis. Advising low-income consumers to purchase healthier but more expensive foods is not a viable long-term strategy for improving population health.

As shown in Fig. 3, there was a direct relation between nutrient density and energy cost expressed in $/4184 kJ (1000 kcal). In general, the least nutrient dense foods provided the most energy per dollar. Those foods included refined grains, sweets and fats. However, there were exceptions. Root vegetables, beans and legumes, pasta, milk and eggs provided adequate nutritional value at low cost. Those foods were featured in the Affordable Nutrition Index.

Nutrient profiling for public health

Capturing nutrient density of foods, even approximately, has been put to a wide range of uses. Among some of the earlier application of NP models were the regulation of nutrition and health claims and marketing and advertising to children[6]. The success of NP-derived labels and 'traffic light' logos at point of sale is a continuing topic for debate[5,49,50].

One recent development has been the use of energy and nutrient density of foods as criteria for taxation of selected food products. For example, in an effort to reduce dietary energy density, Mexico has imposed an

https://doi.org/10.1017/S0029665117000416 Published online by Cambridge University Press

8 % tax on foods with energy density of >1150·6 kJ (275 kcal)/100 g[9]. Included in the legislation were 'non-essential' energy-dense chips and snacks, cakes and pies, cookies, candies, and sweets, chocolate, peanuts and other cereal-based products with substantial added sugar. A tax of 10 % was imposed on low-energy-density sweetened beverages[9].

These initiatives were consistent with the food-based dietary guidelines for Mexico, which recommended reducing the consumption of sweet snacks, cookies and bakery products, replacing soft drinks, juices and aguas frescas with plain water and including vegetables and fresh fruit in every meal. Another recommendation was to eat whole grain tortillas, bread and pasta and to consume legumes such as beans or lentils every day[51].

Whereas energy density was the sole criterion for taxation in Mexico, that will not be the case in Chile. One proposal is to tax all foods with existing black seals, based on the foods' content of saturated fat, total sugar and sodium[52]. Those three elements are components of the SAIN,LIM and the NRF9.3 (NutriScore) NP systems described earlier. The overall nutritional value of foods is better captured by NP than by the energy density metric.

Conclusions

While most prior uses of NP models have been regulatory and educational, NP methods have now been used by the food industry to review and reformulate product portfolios. Expanding from individual foods, NP methodology has been applied to meals, menus and total diets[19]. NP methods on portable apps offer a new way of influencing food purchases at point of sale. These initiatives are consistent with the call by the WHO for greater industry engagement in improving the nutrient density and quality of the global food supply.

Acknowledgements

The author would like to thank Drs. Nicole Darmon and Matthieu Maillot for useful discussions and fruitful collaborations on the many aspects of nutrient profiling of foods.

Financial Support

The symposium on nutrient profiling for public health was supported by the Nestlé Research Center, Lausanne, Switzerland.

Conflicts of Interest

The author has received grants, contracts, honoraria, and consulting fees from numerous food and beverage companies and other commercial and nonprofit entities with interests in diet quality and health. The University of Washington has received grants, donations, and contracts from both the public and the private sector.

Authorship

The author was solely responsible for all aspects of the preparation of this paper.

References

1. Drewnowski A & Fulgoni VL III (2014) Nutrient density: principles and evaluation tools. *Am J Clin Nutr* **99**, 1223s–1228s.
2. Nicklas TA, Drewnowski A & O'Neil CE (2014) The nutrient density approach to healthy eating: challenges and opportunities. *Public Health Nutr* **17**, 2626–2636.
3. The European Parliament and the Council of the European Union (2006) Regulation (EC) no 1924/2006 of the European parliament and of the council of 20 December 2006 on nutrition and health claims made on foods. *Off J Eur Union L* **404**, 9–25.
4. Maschkowski G, Hartmann M & Hoffmann J (2014) Health-related on-pack communication and nutritional value of ready-to-eat breakfast cereals evaluated against five nutrient profiling schemes. *BMC Public Health* **14**, 1178.
5. Mhurchu CN, Mackenzie T & Vandevijvere S (2016) Protecting New Zealand children from exposure to the marketing of unhealthy foods and drinks: a comparison of three nutrient profiling systems to classify foods. *N Z Med J* **129**, 41–53.
6. Royo-Bordonada MA, Leon-Flandez K, Damian J *et al.* (2016) The extent and nature of food advertising to children on Spanish television in 2012 using an international food-based coding system and the UK nutrient profiling model. *Public Health* **137**, 88–94.
7. Pan American Health Organization (2016). Pan American health organization nutrient profile model. http://iris.Paho.Org/xmlui/handle/123456789/18621 (accessed January 2017).
8. French Fund for Food and Health (2017) http://alimentation-sante.Org/2017/03/lexperimentation-en-conditions-reelles-est-arrivee-a-son-terme-le-ffas-a-su-mener-a-bien-la-mission-de-porteur-operationnel-de-ce-vaste-projet/ (accessed March 2017).
9. Batis C, Rivera JA, Popkin BM *et al.* (2016) First-year evaluation of Mexico's tax on nonessential energy-dense foods: an observational study. *PLoS Med* **13**, e1002057.
10. Darmon N, Darmon M, Maillot M *et al.* (2005) A nutrient density standard for vegetables and fruits: nutrients per calorie and nutrients per unit cost. *J Am Diet Assoc* **105**, 1881–1887.
11. Vlassopoulos A, Masset G, Leroy F *et al.* (2017) A nutrient profiling system for the (re)formulation of a global food & beverage portfolio. *Eur J Nutr* **56**, 1105–1122.
12. Masset G, Mathias KC, Vlassopoulos A *et al.* (2016) Modeled dietary impact of pizza reformulations in US children and adolescents. *PLoS ONE* **11**, e0164197.
13. Vlassopoulos A, Masset G, Charles VR *et al.* (2017) A nutrient profiling system for the (re)formulation of a global food and beverage portfolio. *Eur J Nutr* **56**, 1105–1122.
14. US Office of the Federal Register (2016) https://www.Federalregister.Gov/documents/2016/09/28/2016-23365/use-of-the-term-healthy-in-the-labeling-of-human-food-products-request-for-information-and-comments (accessed January 2017).

https://doi.org/10.1017/S0029665117000416 Published online by Cambridge University Press

15. Drewnowski A & Fulgoni V (2008) Nutrient profiling of foods: creating a nutrient-rich food index. *Nutr rev* **66**, 23–39.
16. Drewnowski A. (2009) Defining nutrient density: development and validation of the nutrient rich foods index. *J Am Coll Nutr* **28**, 421s–426s.
17. Drewnowski A, Maillot M & Darmon N (2009) Testing nutrient profile models in relation to energy density and energy cost. *Eur J Clin Nutr* **63**, 674–683.
18. Drewnowski A (2005) Concept of a nutritious food: toward a nutrient density score. *Am J Clin Nutr* **82**, 721–732.
19. Fern EB, Watzke H, Barclay DV *et al.* (2015) The nutrient balance concept: a new quality metric for composite meals and diets. *PLoS ONE* **10**, e0130491.
20. Drewnowski A, Maillot M & Darmon N (2009) Should nutrient profiles be based on 100 g, 100 kcal or serving size? *Eur J Clin Nutr* **63**, 898–904.
21. Maillot M, Darmon N, Darmon M *et al.* (2007) Nutrient-dense food groups have high energy costs: an econometric approach to nutrient profiling. *J Nutr* **137**, 1815–1820.
22. Azais-Braesco V, Goffi C & Labouze E (2006) Nutrient profiling: comparison and critical analysis of existing systems. *Public Health Nutr* **9**, 613–622.
23. Labouze E, Goffi C, Moulay L *et al.* (2007) A multipurpose tool to evaluate the nutritional quality of individual foods: nutrimap. *Public Health Nutr* **10**, 690–700.
24. Scarborough P, Boxer A, Rayner M *et al.* (2007) Testing nutrient profile models using data from a survey of nutrition professionals. *Public Health Nutr* **10**, 337–345.
25. Arambepola C, Scarborough P & Rayner M (2008) Validating a nutrient profile model. *Public Health Nutr* **11**, 371–378.
26. Darmon N, Vieux F, Maillot M *et al.* (2009) Nutrient profiles discriminate between foods according to their contribution to nutritionally adequate diets: a validation study using linear programming and the SAIN,LIM system. *Am J Clin Nutr* **89**, 1227–1236.
27. Francou A, Hebel P, Braesco V *et al.* (2015) Consumption patterns of fruit and vegetable juices and dietary nutrient density among French children and adults. *Nutrients* **7**, 6073–6087.
28. Sluik D, Streppel MT, van Lee L *et al.* (2015) Evaluation of a nutrient-rich food index score in the Netherlands. *J Nutr Sci* **4**, e14.
29. Streppel MT, Sluik D, van Yperen JF *et al.* (2014) Nutrient-rich foods, cardiovascular diseases and all-cause mortality: the Rotterdam study. *Eur J Clin Nutr* **68**, 741–747.
30. O'Sullivan TA, Bremner AP, Bremer HK *et al.* (2015) Dairy product consumption, dietary nutrient and energy density and associations with obesity in Australian adolescents. *J Hum Nutr Diet* **28**, 452–464.
31. Zhou Z, Hu W, Li M *et al.* (2014) Development and validation of a new model of desirable dietary pattern (N-DDP) score for Chinese diets. *Public Health Nutr* **17**, 519–528.
32. USDA Food and Nutrient Database for Dietary Studies, 1.0 (2004) Beltsville, MD. Agricultural research service, food surveys research group. http://www.Ars.Usda.Gov/services/docs.Htm?Docid=12082 (accessed January 2017).
33. Bowman SA, Friday JE & Moshfegh A (2008) *MyPyramid Equivalents database, 2.0 for USDA survey foods, 2003–2004: Documentaiton and user Guide. Food Surveys Research Group*. Beltsville, MD: Beltsville Human Nutrition Research Center, Agricultural Research Service, U.S. Department of Agriculture. http://www.Ars.Usda.Gov/ba/bhnrc/fsrg (accessed January 2017).
34. US Food and Drug Administration (2016). Code of federal regulations, title 21-food and drugs. http://www.Accessdata.Fda.Gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.Cfm?Fr=101.9 (accessed January 2017).
35. ILSI North America (2016). Branded food products database. http://ilsina.Org/our-work/research-tools-open-data/bfpd/ (accessed January 2017).
36. Dietary Guidelines Advisory Committee (2015) Scientific report: Appendix E-3.2: food group contributions to nutrients in USDA food patterns and current nutrient intakes. https://health.Gov/dietaryguidelines/2015-scientific-report/15-appendix-e3/e3-2.asp (accessed January 2017).
37. Nijman CAJ, Zijp IM, Sierksma A *et al.* (2006) A method to improve the nutritional quality of foods and beverages based on dietary recommendations. *Eur J Clin Nutr* **61**, 461–471.
38. The Nestlé nutritional profiling system, its product categories and sets of criteria. http://www.Nestle.Com/asset-ibrary/documents/library/documents/nutrition_health_wellness/nestle-nutritional-profiling-system.Pdf (accessed January 2017).
39. US Food And Drug Administration (2016). Use of the term 'healthy' in the labeling of human food products: guidance for industry. https://www.Fda.Gov/downloads/food/guidanceregulation/guidancedocumentsregulatoryinformation/ucm521692.Pdf (accessed January 2017).
40. Fahmida U, Santika O, Kolopaking R *et al.* (2014) Complementary feeding recommendations based on locally available foods in Indonesia. *Food Nutr Bull* **35**, S174–S179.
41. Food And Drug Administration Law Blog (2017). FDA meeting to discuss the meaning and use of the term 'healthy' for foods. http://www.Fdalawblog.Net/fda_law_-blog_hyman_phelps/2017/02/fda-meeting-to-discuss-the-meaning-and-use-of-the-term-healthy-for-foods.Html (accessed January 2017).
42. US Food and Drug Administration (1994). Guide To Nutrition And Labeling And Education Act (NLEA) requirements. http://www.Fda.Gov/iceci/inspections/inspectionguides/ucm074948.Htm (accessed January 2017).
43. US Food And Drug Administration (2016). Changes to the nutrition facts label. https://www.Fda.Gov/food/guidanceregulation/guidancedocumentsregulatoryinformation/labelingnutrition/ucm385663.Htm (accessed January 2017).
44. Dietary Guidelines Advisory Committee (2015) Scientific Report, Part D. Chapter 1: food and nutrient intakes, and health: current status and trends – continued. https://health.Gov/dietaryguidelines/2015-scientific-report/06-chapter-1/d1-2.Asp (accessed January 2017).
45. Trumbo P, Yates AA, Schlicker S *et al.* (2001) Dietary reference intakes: vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. *J Am Diet Assoc* **101**, 294–301.
46. Trumbo P, Schlicker S, Yates AA *et al.* Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein and amino acids. *J Am Diet Assoc* **102**, 1621–1630.
47. Rayner M, Scarborough P, Stockley L *et al.* (2005) Nutrient profiles: further refinement and testing of model SSCG3D. Final Report. http://www.Food.Gov.Uk/multimedia/pdfs/npreportsept05.Pdf (accessed December 2016).
48. Drewnowski A & Rehm CD (2013) Vegetable cost metrics show that potatoes and beans provide most nutrients per penny. *PLoS ONE* **8**, e63277.
49. Fonds Francais Pour Alimentaiton et la santé. Experimentation logos nutritionnels. http://alimentation-sante.Org/category/experimentation-logos-nutritionnels/ (accessed December 2016).

50. Julia C, Méjean C, Péneau S *et al*. (2016) The 5-CNL front-of-pack nutrition label appears an effective tool to achieve food substitutions towards healthier diets across dietary profiles. *PLoS ONE* **11**, e0157545.
51. Mendoza A, Perez AE, Aggarwal A *et al*. (2017) Energy density of foods and diets in Mexico and their monetary cost by socioeconomic strata: analyses of ENSANUT data 2012. *J Epidemiol Commun Health* [Epublication ahead of print version].
52. The Santiago Times (2017) Chilean government plans to ram through nex tax on sugary foods. http://santiagotimes.Cl/2017/01/17/chilean-government-plans-to-ram-through-new-tax-on-sugary-foods/ (accessed January 2017).

https://doi.org/10.1017/S0029665117000416 Published online by Cambridge University Press