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ORIGINAL ARTICLE

Should nutrient profiles be based on 100 g, 100 kcal or serving size?

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Background/Objectives: Nutrient profiling of foods is defined as the science of ranking or classifying foods based on their nutrient content. Nutrient profiles can be calculated based on 100 g or 100 kcal of food or on standard serving sizes. The objective of this study was to compare the performance of nutrient profiles based on 100 g, 100 kcal and government-mandated serving sizes, and to identify the optimal base of calculation.
Subjects/Methods: Nutrient profiles tested were composed of positive subscores based on nutrients to encourage and negative subscores based on nutrients to limit. Alternative profiles, computed using different bases of calculation, were used to rank order 378 commonly consumed foods from a food frequency instrument. Profile performance was tested with respect to the foods' energy density.
Results: Serving sizes, defined by the US Food and Drug Administration as reference amounts customarily consumed (RACC), were inversely linked to energy density of foods. Positive subscores based on 100 kcal were equivalent to those calculated using RACC values. Negative subscores performed better when based on 100 g as opposed to 100 kcal.
Conclusions: Models based on serving sizes and on 100 kcal were preferable for positive subscores and models based on 100 g of food were preferable for negative subscores. RACC-based profiles may represent an attractive option for the US consumer.
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Keywords: nutrition requirements; food legislation; nutritional quality; nutrient profile

Introduction

Nutrient profiling is defined as the science of ranking or classifying foods based on their nutrient composition (Food Standards Agency, 2005). It will shortly become the basis for regulating health claims in the European Union (EU). In early 2009, only foods with specified nutrient profiles will be deemed capable of bearing a claim whereas other foods will be disqualified (The European Parliament and the Council of the European Union, 2006).

Nutrient profiles, based on the prevailing scientific knowledge about diets and health, are generally based on nutrients to limit, nutrients known to be beneficial to health or on some combination of both (Gazibarich and Ricci, 1998; Scheidt and Daniel, 2004; Darmon *et al*., 2005; Drewnowski, 2005; Rayner *et al*., 2005; Labouze *et al*., 2007; Maillot *et al*., 2007; Netherlands nutrition center, 2007; Nijman *et al*., 2007; Stockley, 2007). Developing a profiling system for individual foods poses a number of challenges. These include, but are not limited to, the selection of qualifying and disqualifying nutrients, the choice of reference daily values, the choice of a threshold or a scoring algorithm (Drewnowski, 2007; Garsetti *et al*., 2007; EFSA, 2008) and testing and validation of the chosen approach (Azais-Braesco *et al*., 2006; Volatier *et al*., 2007; Scarborough *et al*., 2007a, b; Arambepola *et al*., 2008; Drewnowski *et al*., 2008; Maillot *et al*., 2008).

Selecting the basis of calculation for nutrient profiling poses a special problem. Existing profile models have been calculated based on 100 kcal, 100 g and on serving sizes. Early on, Hansen *et al*. (1979) noted that calculations based

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on 100 kcal were the only way to compare the nutrient content of one food with that of another. Later, choices of reference amounts were influenced, in part, by the local regulatory climate. In the EU, nutrition labeling is provided per 100 g; in the United States, such information is provided only per serving size, defined by the Food and Drug Administration (FDA) as reference amount customarily consumed or RACC.

Each method has its own advantages and disadvantages. Expressing the nutrient content of foods in relation to energy (per 100 kcal/100 kJ or % energy for macronutrients) allows for ready comparisons with nutrient recommendations and guidelines, typically expressed per 2000 kcal daily ration. However, foods and beverages with low energy content will be scored disproportionately high by virtue of their low energy density. The 100 kcal basis may be in excess of the portion typically consumed, notably for vegetables and fruits.

Profiles calculated based on the weight or volume of food (per 100 g/100 ml) are consistent with nutrition labeling regulation in the EU. However, typical serving sizes for different foods deviate very significantly from the 100 g norm. For example, serving sizes for oils, spreads, cheeses and breakfast cereals are typically much smaller than 100 g. By contrast, serving sizes for yogurts, soups, juices and beverages are well in excess of 100 g. Differences in water content can greatly influence calculations of nutrient content expressed on a weight/volume basis, thereby confounding comparisons between, for example, solid cheese and fluid milk. The disadvantage is greater for across the board as opposed to category-based schemes because the water content is more variable between than within food groups (Garsetti *et al*., 2007). However, this disadvantage can be overcome partly if beverages are considered separately from solid foods. For these reasons, profiles based on 100 g have been forced to include adjustments for oils and spreads on one hand, and beverages on the other.

Expressing nutrient content on a per serving/portion basis is the only approach that is directly related to the quantity of food typically consumed. As such, it can be an important determinant of the food's potential to affect the overall dietary balance, an important point mentioned in Article 4 of the European Commission proposal 1924/2006 (The European Parliament and the Council of the European Union, 2006). Although many food products are labeled in this way, as yet there are no standardized serving/portion sizes for different groups of food products defined at the EU level. As a result, the current European Food Safety Authority preference is for systems based on weight/volume, or energy, or on some combination thereof (EFSA, 2008).

The choice of reference amounts may have a major impact on the eligibility of different foods or food groups for bearing health claims. Yet the impact on different calculation bases on model performance has not been formally studied. Given the absence of standardized portion sizes in the EU, the present calculations were based on serving sizes (RACC values) approved by the US FDA and, in current use, on Nutrition Facts Panel in the United States. The goal was to compare the performance of positive and negative profile subscores, each calculated based on 100 kcal, 100 g and RACC. One question was whether the basis of calculation would have a different impact when applied to scores based on a variable number of nutrients to encourage as opposed to nutrients to limit.

Materials and methods

Food database

The food list was based on 378 component foods of a food frequency questionnaire developed by the Fred Hutchinson Cancer Research Center (Kristal *et al*., 1999; Patterson *et al*., 1999). Foods are selected for inclusion in food frequency questionnaire instruments if they are frequently consumed by large numbers of people, contain nutrients of interest and their consumption varies from person to person (Willet, 1998). The Fred Hutchinson Cancer Research Center instrument (G-SEL version) represented the major food groups: grains, vegetables, fruits, dairy, meat and fish, fats and oils, and sweets. Fortified products, including ready-to-eat cereals, were included, whereas diet beverages, tea, coffee and drinking water were excluded (Patterson *et al*., 2003).

Nutrient composition database

Nutrient composition of the 378 foods was determined using the US Department of Agriculture database SR-18 (USDA, 2007) and the Food and Nutrition Database for Dietary Studies 2.0 (USDA, 2006). These data were used to calculate positive and negative nutrient profile scores and the energy density of foods (USDA, 2006; Monsivais *et al*., 2007).

Reference amounts

All scores were calculated per 100 kcal, per 100 g and per RACC. The US FDA uses 139 different RACC values (FDA, 2002, 2007a, 2008). 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 fruits (120 g), or milk, juices and other beverages (240 g).

Nutrient score algorithms

Table 1 summarizes four alternative nutrient-rich (NR) subscores based on a variable number of nutrients to encourage ($n = 6$, 9, 11 and 15) and nutrients to limit (LIM) subscores based on a fixed number ($n = 3$) of nutrients to limit. The NR6 subscore was based on six nutrients that enter into the FDA definition of healthy foods (FDA, 2002). The NR9 subscore was based on nutrients of concern as identified by the 2005 Dietary Guidelines for Americans. The NR15 subscore was the previously published naturally NR index,

Table 1 Index nutrients in selected NR*n* and LIM scores

Model	*Macronutrients*	*Vitamins*	*Minerals*	*Nutrients to limit*
NR6	Protein, fiber	A, C	Ca, Fe	
NR9	Protein, fiber	A, C, E	Ca, Fe, Mg, K	
NR11	Protein, fiber	A, C, E, B_{12}	Ca, Fe, Mg, Zn, K	
NR15	Protein, fiber, MUFA	A, C, D, E, thiamin, riboflavin, B_{12}, folate	Ca, Fe, Zn, K	
LIM				Saturated fat added sugar, Na

Abbreviations: LIM, limited nutrient score; MUFA, monounsaturated fatty acids; NR, nutrient-rich score.

Table 2 Reference daily values for nutrients, based on 2000 kcal diet

Nutrient	*RDV*
Protein	50 g
Fiber	25 g
MUFA	20 g
Vitamin A	5000 IU
Vitamin C	60 mg
Vitamin D	400 IU (10 μg)
Vitamin E	30 IU (20 mg)
Thiamin	1.5 mg
Riboflavin	1.7 mg
Vitamin B_{12}	6 μg
Folate	400 μg
Calcium	1000 mg
Iron	18 mg
Zinc	15 mg
Potassium	3500 mg
Magnesium	400 mg

Abbreviations: MUFA, monounsaturated fatty acids; RDV, reference daily value.

based on protein, fiber, vitamins A, C, D, E and B_{12}, folate, calcium, iron, potassium and zinc (Drewnowski, 2005). The negative LIM subscore was based on saturated fat, added sugar and sodium (Maillot *et al*., 2007; AFSSA, 2008).

The NR*n* subscores were based on unweighted arithmetic means of percent recommended daily values for *n* index nutrients (Darmon *et al*., 2005). The LIM scores were unweighted arithmetic means of percentage maximum recommended values for nutrients to limit (Maillot *et al*., 2007; AFSSA, 2008). Reference daily values for qualifying nutrients are summarized in Table 2. They were based on the recommended values set for nutrition labeling in the United States (FDA, 2002, 2007b). The maximum recommended values for potentially disqualifying nutrients were 10% of energy intake for each of the added sugars and saturated fats and 6 g/d for salt. This translated into 20 g of saturated fat, 50 g of added sugar and 2400 mg of sodium based on a mean daily energy intake of 2000 kcal (Drewnowski *et al*., 2008). Profile algorithms are shown in Table 3.

Statistical analyses
Analyses were performed using SAS software version 9.1 (SAS institute, Cary, NC, USA). Relations among nutrient scores were based on Spearman non-parametric correlations to estimate to what extent two scores ranked the same set of foods in a similar way.

Results

Reference amounts customarily consumed values for 378 foods and the foods' energy density were inversely linked (Spearman correlation = −65%). Figure 1a shows the inverse relation between RACC and energy density and indicates the specific position of some representative foods. Soft drinks, juices, yogurts and soups with a high water content and low energy density had RACC values in the 200–240 g range. Fruits and mixed dishes had RACC values in excess of 100 g. By contrast, meats (85 g), vegetables (85 g), cheeses (30 g), ready-to-eat cereals (30 g), dried fruits and nuts had RACC values well below 100 g. The RACC value for oil was 15 g.

Figure 1b shows the relation between energy expressed per 100 g (standard measure of energy density) and energy per RACC. Energy content of foods was subject to less variability when expressed per RACC (s.d. = 86.2) than when expressed per 100 g (s.d. = 166.6). The use of RACC values effectively normalized major differences in energy density across food groups.

Positive NR*n* subscores calculated using RACC were therefore highly correlated with NR*n* subscores based on 100 kcal. Figure 2a shows these relations for NR6 scores, both plotted along logarithmic scales. The nature of the relation was independent of the number of nutrients included in the score, although its strength slightly decreased as the number of nutrients increased. Spearman coefficients between NR*n* (RACC) and NR*n* (100 kcal) were 76, 74, 75 and 67% for $n = 6$, 9, 11 and 15, respectively.

Figure 2b shows the relation for NR6 scores calculated using 100 g and those calculated based on RACC. Compared with RACC-based scores, positive scores based on 100 g underestimated the nutrient value of beans, fruits, soups and yogurts, which were each consumed in amounts greater than 100 g. By contrast, 100 g-based scores gave an advantage to beneficial nutrients in all the foods that had a RACC value lower than 100 g, not only vegetable and fish, but also cheese, croissant and chocolate bar. The correlations between NR*n* (RACC) and NR*n* (100 g) were lower than between NR*n* (RACC) and NR*n* (100 kcal) and in the order of 63, 60, 63 and 52% for $n = 6$, 9, 11 and 15, respectively.

Table 3 Algorithms for positive NR*n* and negative LIM scores

Score	*Algorithm*	*Reference amount*	*Comment*
NRn			
$NRn_{(100\,g)}$	$(\sum_{1-n} (Nutrient_i/RDV_i)/n) \times 100$	100 g	$NR_{(100\,g)}$ based on 100 g of food; $Nutrient_i$ = content of nutrient *i* in 100 g edible portion; RDV_i = recommended daily values for nutrient *i* (see Table 3); *n* = the number of nutrients
$NRn_{(100\,kcal)}$	$(NRn_{(100\,g)}/ED) \times 100$	100 kcal	$NR_{(100\,kcal)}$ based on 100 kcal of food; $NRn_{(100\,kcal)} = NRn_{(100\,g)}$ divided by energy density (ED, kcal/100 g)
$NRn_{(RACC)}$	$(NRn_{(100\,g)}/100) \times RACC$	RACC	$NRn_{(RACC)} = NRn_{(100\,g)}$ divided by RACC (in g)
LIM			
$LIM_{(100\,g)}$	$(\sum_{1-3} (L_i/MRV_i)/3) \times 100$	100 g	$LIM_{(100\,g)}$ based on 100 g of food; L_i = content of limiting nutrient *i* in 100 g of edible portion of food; *i* = 1–3; MRV_i = recommended daily values for nutrient *i* (see Table 3).
$LIM_{(100\,kcal)}$	$(LIM_{(100\,g)}/ED) \times 100$	100 kcal	LIM score based on 100 kcal of food
$LIM_{(RACC)}$	$(LIM_{(100\,g)}/100) \times RACC$	RACC	Based on MRVs and on RACC

Abbreviations: NR, nutrient-rich score; LIM, limited nutrient score; MRVs, maximum recommended values; RACC, reference amounts customarily consumed; RDV, reference daily value.

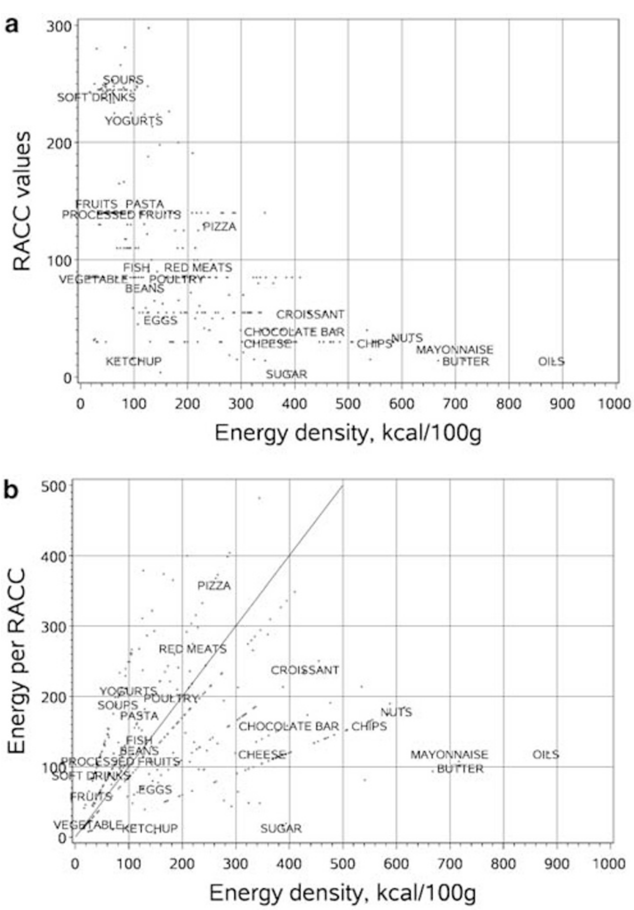

Figure 1 Relation between RACC values (in g) and energy density (kcal/100 g) of foods (**a**, Spearman coefficient = −65%) and between energy content per RACC and energy density (**b**, Spearman coefficient = 52%). RACC, reference amounts customarily consumed.

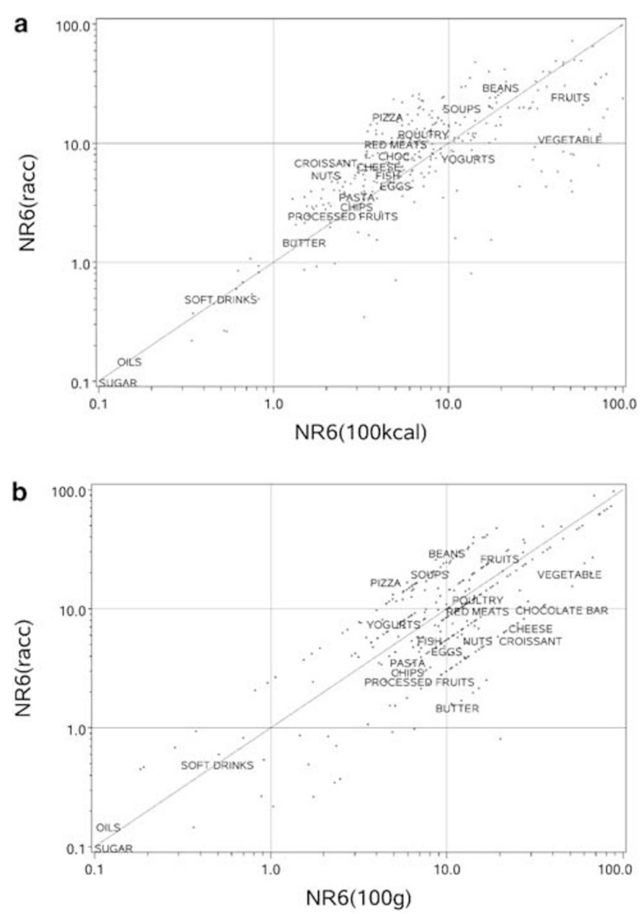

Figure 2 Relation between NR6 calculated per RACC and NR6 calculated per 100 kcal (**a**, Spearman coefficient = 76%) or per 100 g (**b**, Spearman coefficient = 63%). RACC, reference amounts customarily consumed.

As a result, positive subscores calculated based on 100 kcal were, for most foods, equivalent to calculations using RACC values. The exceptions were low-energy-density vegetables and fruits that had a higher score when expressed per 100 kcal than per RACC. Calculating NR subscores per 100 kcal was a better option than by 100 g. As indicated in Figure 2a, the 100 kcal approach seemed to favor lower energy density foods, that is fruits, vegetables, yogurts and eggs. By contrast, the 100 g approach was sensitive neither to calories, nor to the amounts customarily consumed.

Figure 3 shows the systematic relation between the LIM score based on RACC and LIM scores calculated per 100 g (panel A) and per 100 kcal (panel B). Compared with a RACC-based calculation, both the LIM score based on 100 g and that based on 100 kcal underestimated the content of nutrients to limit in foods with big portion sizes such as yogurts (RACC = 220 g) and some mixed dishes. The LIM score per 100 g penalized virtually all energy-dense foods, whereas the LIM score per 100 kcal penalized only some energy-dense foods (ketchup, mayonnaise and sugar) and gave an advantage to others (chips, chocolate bar and croissant). Red meats and fatty meats (RACC = 85 g) were penalized by the 100 g LIM score but were advantaged by the 100 kcal LIM score. On the one hand, the LIM score per 100 kcal penalized foods and beverages of low energy density that contained small amounts of sugar or sodium such as pickles, sauerkraut and vegetable juices and, to a lower extent, canned vegetables and beans. On the other hand, the LIM score based on 100 g was extremely unfavorable to oils (RACC = 15 g), nuts (RACC = 30 g), cheeses (RACC = 30 g) and ready-to-eat cereals (RACC = 30 g). In addition, it minimized the added sugar content of yogurts (RACC = 220 g), processed fruits (RACC = 140 g) and soft drinks (RACC = 240 g).

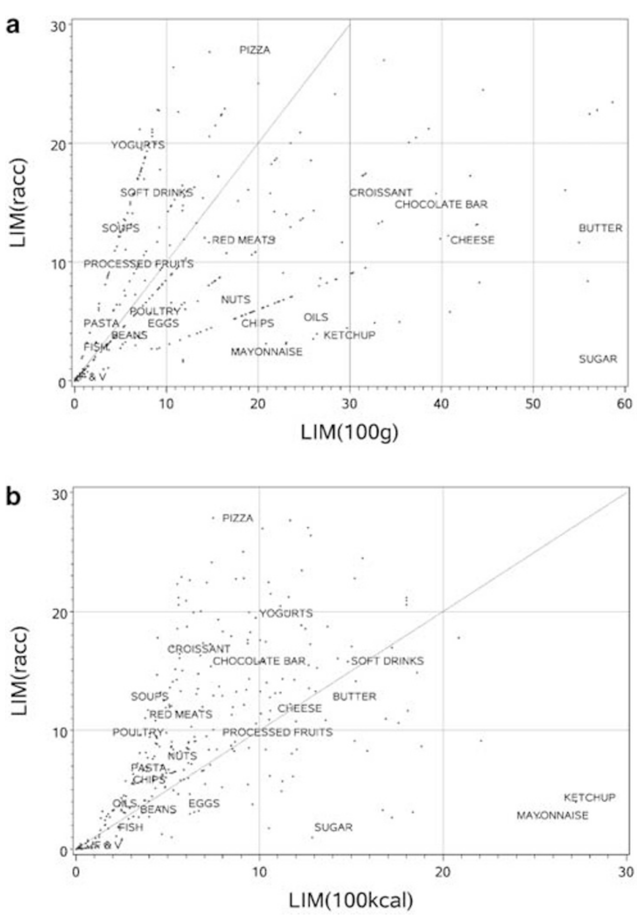

Figure 3 Relation between LIM calculated per RACC and LIM calculated per 100 kcal (**a**, Spearman coefficient = 71%) or per 100 g (**b**, Spearman coefficient = 79%). RACC, reference amounts customarily consumed.

Discussion

Profiling algorithms are commonly based on some combination of nutrients to encourage and nutrients to limit. The choice of reference amounts (100 g, 100 kcal or serving size) in calculating positive and negative subscores lies at the heart of nutrient profiling. In the EU, nutrition labeling is provided per 100 g; in the United States, the nutrition facts label is based on serving sizes or RACC. Expressing nutrient profiles per RACC is not an option available in the EU.

Negative subscores, composed of nutrients to limit and based on 100 g, were strongly correlated with energy density of foods, whereas those based on RACC were not (Drewnowski *et al*., 2008). Consistent with those prior findings, the present data showed that the LIM score, when expressed on a per 100 g basis, penalized all energy-dense foods, whereas the LIM score expressed per 100 kcal penalized only some of them and gave an advantage to others.

In the absence of government-mandated RACC values, the preferred option for negative subscores may be 100 g rather than 100 kcal. Profiles based on 100 g are more consistent with the EU food labeling systems but penalize energy-dense foods consumed in small quantities (nuts, dried fruits and cheeses) while giving overly favorable scores to foods containing added sugar that are consumed in volumes in excess of 100 g. Sweetened beverages (RACC = 240 g) greatly benefit from such a scoring system. Thus, correction could be warranted for nuts, oils and cheeses (divide the negative subscore) and for sugar-containing beverages (multiply the negative subscore). Indeed, to take those biases into account, the latest version of the UK Food Safety Agency score multiplies the negative score for beverages by a factor of 2 (Scarborough *et al*., 2007a). Similarly, the French AFSSA profile multiplies the negative LIM score for beverages by a factor of 2.5 (AFSSA, 2008). Models based on appropriate serving sizes would be more logical; however, that cannot be done in the EU at this time.

Calories were the preferred option of positive subscores, based on nutrients to encourage. Given that RACC values

are a rough inverse of energy density, positive subscores based on 100 kcal and those based on RACC were largely equivalent. Both calculation methods yielded scores that gave higher rankings to vegetables and fruits and lower rankings to energy-dense foods. Instead of developing models based on 100 g, EU researchers might investigate the performance of models based on 100 kcal as a potential alternative to attempting to develop harmonized European portions for every country.

Composite nutrient profiles are usually calculated by subtracting sums or means of positive and negative subscores, or by calculating a ratio between the means. The choice of algorithm may have a further impact on profile performance. Although the Food Standard Agency score was a simple arithmetic difference between the positive and negative subscores (Rayner *et al*., 2005), alternative ways of combining the two subscores are available and await further testing. Composite models based on ratio scores might offer another viable option, as they remove the need for a reference amount standard (Scheidt and Daniel, 2004). However, dividing or subtracting subscores presents the disadvantage of masking the information provided by each subscore. Another possibility is to keep intact this information without combining the scores (Labouze *et al*., 2007). This later approach had the preference of the French regulatory agency AFSSA, which sets thresholds for NR*n* (5% mean daily value in 100 kcal of food) and for LIM (7.5% of maximum recommended value per 100 g) to arrive at a qualifying algorithm (AFSSA, 2008). Weights can also be attributed to nutrients based on the biological quality of nutrients, their bioavailability and their ubiquity in the food supply (Padberg *et al*., 1993; Gazibarich and Ricci, 1998). However, finer decisions regarding optimal performance of closely linked models will need to be resolved through the use of validation techniques that relate nutrient profiles to independent measures of a healthy diet (Volatier *et al*., 2007; Arambepola *et al*., 2008; Maillot *et al*., 2008).

Although the European commission is now seeking a pass/fail score to regulate access to health claims, the ranking of foods by nutrient quality can also be adapted for other purposes. It may become a rationale for food taxation (Mytton *et al*., 2007) or a user-friendly tool for consumer education and guidance (FSA, 2007). One innovative approach is to use nutrient profiles to help consumers identify foods of optimal nutritional quality at an affordable price (Maillot *et al*., 2008). US consumers are also looking for a more nuanced yet simple and at-a-glance index of the nutrient quality of foods (Drewnowski, 2007; FDA/CFSAN, 2007). It remains to be seen whether the nutrient profiling approach will change food-purchasing patterns, leading to measurable changes in diet quality. Translating the concept of nutrient density first into a working algorithm for health claims or other regulatory aspects and then into a food guidance system is the main challenge of nutrient profile design.

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