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Food Compass is a nutrient profiling system using expanded characteristics for assessing healthfulness of foods

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Nutrient profiling systems (NPS) aim to discriminate the healthfulness of foods for front-of-package labelling, warning labels, taxation, company ratings and more. Existing NPS often assess relatively few nutrients and ingredients, use inconsistent criteria across food categories and have not incorporated the newest science. Here, we developed and validated an NPS, the Food Compass, to incorporate a broader range of food characteristics, attributes and uniform scoring principles. We scored 54 attributes across 9 health-relevant domains: nutrient ratios, vitamins, minerals, food ingredients, additives, processing, specific lipids, fibre and protein, and phytochemicals. The domain scores were summed into a final Food Compass Score (FCS) ranging from 1 (least healthy) to 100 (most healthy) for all foods and beverages. Content validity was confirmed by assessing nutrients, food ingredients and other characteristics of public health concern; face validity was confirmed by assessing the FCS for 8,032 foods and beverages reported in NHANES/FNDDS 2015–16; and convergent and discriminant validity was confirmed from comparisons with the NOVA food processing classification, the Health Star Rating and the Nutri-Score. The FCS differentiated food categories and food items well, with mean ± s.d. ranging from 17.1 ± 17.2 for savoury snacks and sweet desserts to 81.6 ± 16.0 for legumes, nuts and seeds. In many food categories, the FCS provided important discrimination of specific foods and beverages as compared with NOVA, the Health Star Rating or the Nutri-Score. On the basis of demonstrated content, convergent and discriminant validity, the Food Compass provides an NPS scoring a broader range of attributes and domains than previous systems with uniform and transparent principles. This publicly available tool will help guide consumer choice, research, food policy, industry reformulations and mission-focused investment decisions.

Diet is a leading modifiable cause of poor health globally[1]. While broad outlines of a healthful diet are clear—for example, eat more fruits and vegetables, and avoid soda[2]—ambiguity exists on how to distinguish many other food groups, packaged and processed foods, and restaurant and mixed-food dishes, which together represent the majority of most diets. Clear metrics to characterize the healthfulness of these food items as well as groups of items, such as whole meals, diets or company product portfolios, are essential. Such metrics can help inform consumer choices; define incentives in worksite wellness, health care or nutrition assistance programmes; promote industry reformulations and compliance with societal targets; guide public health policies such as front-of-package (FOP) labelling, food procurement and school meal standards, taxation, and marketing restrictions; inform agricultural and trade practices; and guide environmental, social and corporate governance (ESG) investment decisions[3–8].

Several approaches to assessing the healthfulness of foods rely on isolated single nutrients, such as nutrient labelling (for example, Nutrition Facts) or FOP labels based on single nutrient thresholds (for example, UK 'traffic light' labels and Chile and Mexico's 'black box' warnings)[9]. Other approaches rely on general determinations of food processing[10]. Because assessments of healthfulness based on single nutrients in isolation or broad processing categories can have limited applicability, nutrient profiling systems (NPS) have emerged as a more comprehensive approach. NPS represent "the science of classifying or ranking foods according to their nutritional composition for reasons related to preventing disease and promoting health."[3,11] NPS provide quantitative algorithms to score food products on the basis of the presence and/or amounts of attributes scored as beneficial (for example, selected vitamins and fruit content) or detrimental (for example, calories, total fat, saturated fat, salt and sugar)[5].

NPS are gaining momentum as major tools for policy actions—for example, in the European Union (Nutri-Score, Keyhole and others), North America (Guiding Stars), South America (Pan American Health Organization system and Chile stage III systems), Australia and New Zealand (Health Star Rating (HSR)), Asia (Healthier Choice Symbol) and the Middle East (Waqeya). Yet, limitations and gaps remain. In the European Union, for example, there is considerable ongoing discussion and controversy over the best NPS for a harmonized approach to FOP nutrition labelling[12]. Of numerous NPS models evaluated by the World Health Organization[3], the majority (84%) had not undergone any type of validation, such as for content validity (including nutrients and/or dietary factors of public health concern), criterion validity (the contents are compared against a 'gold standard' reference where possible), convergent and discriminant validity (comparing the NPS with other scoring systems) or construct validity (evaluating the NPS against population diet quality indices or health outcomes)[13,14]. In addition, most NPS score a relatively small number of nutrients and ingredients; several prioritize nutrients with outdated evidence for health impacts (such as total calories or total fat); and most score nutrient contents

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Table 1 | Domains and attributes of the FCS

Nutrient ratios	Vitamins (top five)	Minerals (top five)	Food-based ingredients	Additives	Processing	Specific lipids (0.5 weight) (top three)	Fibre and protein (0.5 weight)	Phytochemicals (0.5 weight)
Unsaturated: saturated fat ratio	Vitamin A	Calcium	Fruits	Added sugar	NOVA classification	Alpha-linolenic acid	Total fibre	Total flavonoids
Fibre: carbohydrate ratio	Thiamine (B_1)	Phosphorus	Vegetables, non-starchy	Nitrites	Fermentation	Eicosapentaenoic acid + docosahexaenoic acid	Total protein	Total carotenoids
Potassium: sodium ratio	Riboflavin (B_2)	Magnesium	Beans and legumes	Artificial sweeteners, flavours or colours	Frying	Medium-chain fatty acids		
	Niacin (B_3)	Iron	Whole grains	Partially hydrogenated oils		Dietary cholesterol		
	Vitamin B_6	Zinc	Nuts and seeds	Interesterified or hydrogenated oils		Trans fats		
	Folate (B_9)	Copper	Seafood	High-fructose corn syrup				
	Cobalamin (B_{12})	Selenium	Yogurt	Monosodium glutamate				
	Vitamin C	Sodium	Plant oils					
	Vitamin D	Potassium	Refined grains					
	Vitamin E	Iodine	Red or processed meat					
	Vitamin K							
	Choline							

Across 9 domains, 54 individual attributes were assessed per 100 kcal (418.4 kJ) of food product, with scoring from 0 to 10 for beneficial attributes, −10 to 0 for harmful attributes and −10 to 10 for attribute ratios that could range from harmful to beneficial. Each domain received a score, calculated as the average of all attributes in that domain (or for food ingredients, as the sum, given that the contents of ingredients are interdependent). For vitamins and minerals, the domain score was calculated from the highest (absolute value—that is, negative or positive) five attribute scores; and for specific lipids, from the highest three attribute scores (Supplementary Table 3). Attributes with emerging evidence for health impacts (five additives, as well as fermentation and frying as processing methods) were scored using half-weights. All domain scores were then summed, using equal weights for the first six domains and half-weights for the latter three domains (Methods). The final FCS was scaled across all food and beverage items to range from 1 (least healthful) to 100 (most healthful). For the full scoring details, see Supplementary Table 3. Potassium and sodium were included both as 'Nutrient ratios' given evidence for their biologic interaction and separately as 'Minerals' given evidence that their absolute intakes also influence health. Carbohydrate and fibre were included as 'Nutrient ratios' given evidence that their ratio predicts the healthfulness of carbohydrate-rich foods, and separately as total fibre (in 'Fibre and protein') given evidence that the absolute intake of dietary fibre, but not total carbohydrate, influences health. Partially hydrogenated oils were included in addition to trans fat content (scored −10 to 0 in 'Specific lipids') on the basis of emerging evidence that industrial trans fats may have greater adverse health effects than naturally occurring trans fats, and that the presence of such partially hydrogenated oils may serve as a marker of more intensive and potentially adverse industrial processing.

per gram, which can be strongly influenced by water content[4,5,15–17]. Most widely used NPS also have varying attribute criteria and scoring principles for different, arbitrarily grouped food categories (from 4 to 33), which increases subjectivity and inconsistency and limits consistent scoring of mixed foods or meals. Few existing NPS incorporate evidence on the diversity of food attributes relevant to health, such as the presence of polyphenols or other phytonutrients, probiotics, other additives, or processing characteristics that may be adverse (for example, ultraprocessing) or beneficial (for example, fermentation).

To address these gaps, we developed the Food Compass, a comprehensive NPS incorporating an expanded assessment of nutrient and ingredient characteristics, additional food components and processing parameters in a uniform fashion across food categories, to help guide healthy food choices; industry reformulations; environmental, social and corporate governance metrics; and policy actions. Relevant nutritional attributes were selected, scoring principles identified and an algorithm established on the basis of an assessment of existing NPS, dietary guidelines, health claims and diet–health relationships. Testing and validation were performed on the basis of content validity for nutrients, food ingredients and other characteristics of public health concern; face validity from the scoring of 8,032 unique foods and beverages in a nationally representative US database; and convergent and discriminant validity from comparisons with the NOVA food processing classification and the HSR and Nutri-Score NPS.

Results

Food Compass attributes, domains and scoring. Relevant attributes and scoring principles were developed on the basis of an assessment of more than 100 reported NPS[4,9], including 7 widely used NPS of diverse origins (Supplementary Table 1); a systematic review of national and international dietary guidelines[2]; nutrient requirements for health claims (Supplementary Table 2); and an assessment of nutrients, ingredients and other food characteristics linked to health outcomes[18–21]. The final algorithm incorporated 54 attributes across 9 domains (Table 1 and Fig. 1). Of the domains, 'Nutrient ratios' included measures of fat quality (unsaturated:saturated fat ratio), carbohydrate quality (carbohydrate:fibre ratio) and mineral quality (potassium:sodium ratio). 'Vitamins' and 'Minerals' included major nutrients related to undernutrition and chronic diseases. 'Food-based ingredients' included food groups with probable or convincing evidence for impacts on chronic diseases including cardiovascular diseases, type 2 diabetes or cancers[18,22]. 'Additives' included factors with evidence for health harms (for example, added sugar and nitrites in processed meats) or emerging but not definitive evidence for harms and/or potential markers of adverse industrial processing (for example, artificial sweeteners, flavours or colours). 'Processing' metrics included the NOVA classification, as well as fermentation and frying as emerging processing characteristics with health implications. The remaining three domains incorporated specific lipids, fibre and protein, and phytochemicals, each given a half-weight on the basis of less formally recognized

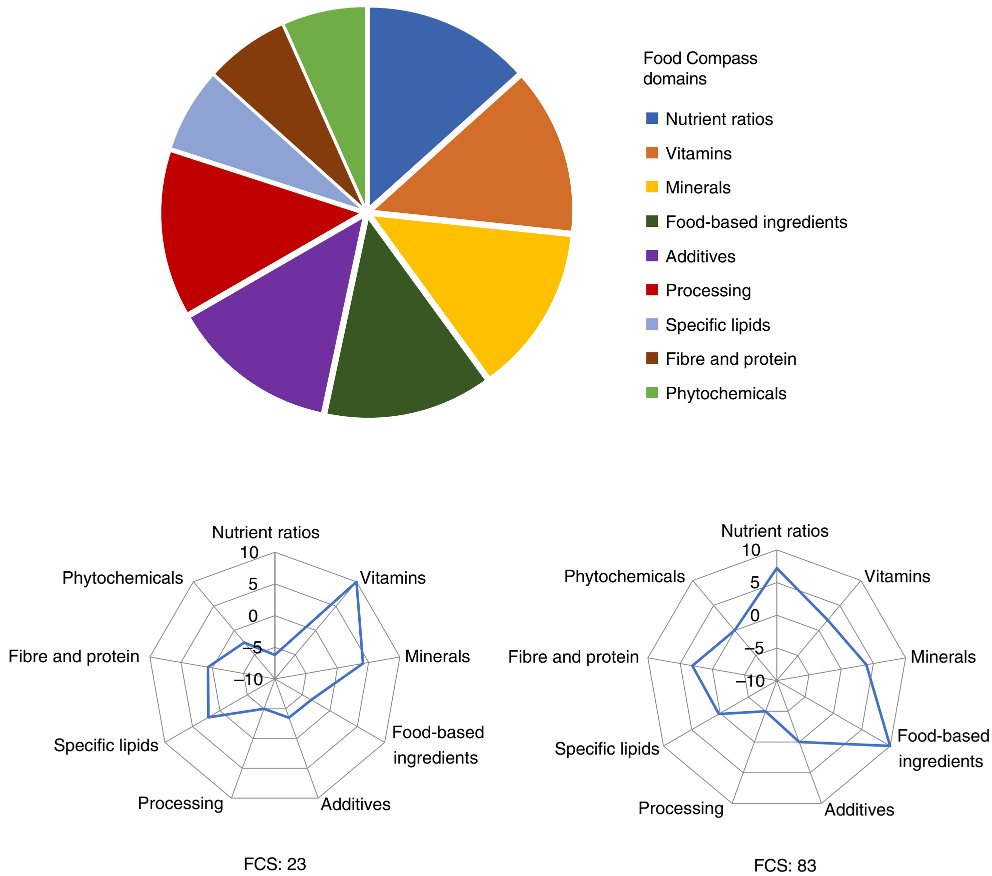
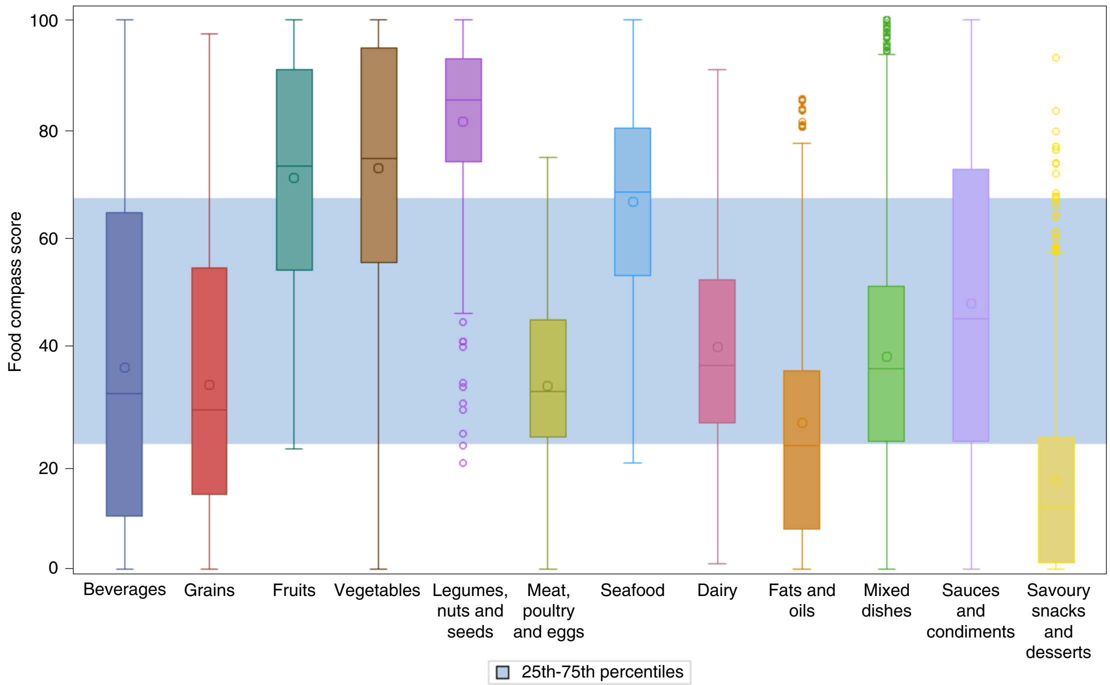


Fig. 1 | Domains of the Food Compass. The Food Compass scores food items across nine domains (top), with six domains equally weighted and three domains each given a half-weight on the basis of more modest relative health effects. Each domain score is calculated as the average of the scores of the specific attributes within that domain; sample spider plots of the nine domain scores for two food products are shown (bottom). The nine domain scores are summed and scaled to calculate a final FCS, scaled to range from 1 (least healthful) to 100 (most healthful).

evidence or dietary guidance supporting health associations, specific target intakes or health effects independent of the other attributes and domains. The full details of the scoring algorithm are in Supplementary Table 3, and score distributions for each domain for the 8,032 unique foods and beverages in the Food and Nutrient Database for Dietary Studies (FNDDS) are shown in Supplementary Fig. 1. Three example foods with details of attribute values, attribute scores and domain scores are given in Supplementary Table 4. Summed across domains, the overall score for any item could range from −35 to 60; the final Food Compass Score (FCS) was scaled for interpretability to range from 1 (least healthful) to 100 (most healthful).

Testing and validation using NHANES. To assess usefulness and validity, we applied the Food Compass to all 8,032 unique foods and beverages in FNDDS. Overall, the mean ± s.d. FCS was 46.1 ± 28.7 (median, 43.6) (Supplementary Table 5). Among 12 major food categories, the FCS varied from 17.1 ± 17.2 for savoury snacks and sweet desserts to 81.6 ± 16.0 for legumes, nuts and seeds (Fig. 2). The interquartile range (25th, 75th percentiles) was the narrowest for savoury snacks and sweet desserts (2.2 ± 24.6) and meat, poultry and eggs (24.9 ± 45.9) and was the broadest for beverages (10.5 ± 65.2). Within each food category, the FCS distributions were relatively normal and also broad, often as low as 1.0 (exceptions included dairy, 2.0; legumes, nuts and seeds, 20.2; seafood, 20.2; and fruits 22.8) and as high as 100 (exceptions included meat, poultry and eggs, 75.2; fats and oils, 85.7; dairy 91.1; savoury snacks and sweet desserts, 93.1; and grains, 97.5). On the basis of the observed ranges, FCS ≥ 70 was selected as a reasonable cut-off point for foods or beverages to be encouraged; FCS = 31–69, to be consumed in moderation; and FCS ≤ 30, to be minimized.

Subcategorization into 44 food subcategories supported further discrimination and specificity of the FCS (Fig. 2). For example, the mean ± s.d. FCS was 28.8 ± 29.2 for sugar-sweetened sodas and energy drinks versus 76.7 ± 18.4 for 100% fruit or vegetable juices; 26.9 ± 4.7 for beef, 42.3 ± 10.9 for poultry and 67.1 ± 17.3 for seafood; and 48.8 ± 13.6 for starchy vegetables versus 91.3 ± 11.7 for green vegetables. Among fruits, nearly all raw fruits received an FCS of 100, while higher-sugar fruits such as bananas, dates and figs received a lower FCS (but still >70). Examples of scores are given in Supplementary Table 6 and Supplementary Fig. 2. Among beverages, for instance, the FCS for low-sodium tomato juice was 100; carrot juice, 89; apple juice, 65; a packaged fruit juice drink, 13; and most energy drinks, sports drinks and colas, 1–2. Among grain-based products, a whole-oat cereal received a 91; plain instant oatmeal with water, 89; whole-grain pasta, 80; whole-wheat bread, 61; cooked noodles, 28; plain waffles, 16; white rice with margarine, 8; and pita bread, 1. Other examples among fruits, mixed dishes and savoury snacks and sweets are also shown. As one illustrative example, the scores for bulgur (a whole grain generally encouraged in dietary guidance) and sweet potato chips (a savoury snack generally limited in dietary guidance) were both 68. A more detailed discussion of their comparative nutritional profiles is provided in Supplementary Text 2. The scores for all 8,032 foods and beverages are provided in Supplementary Table 7.



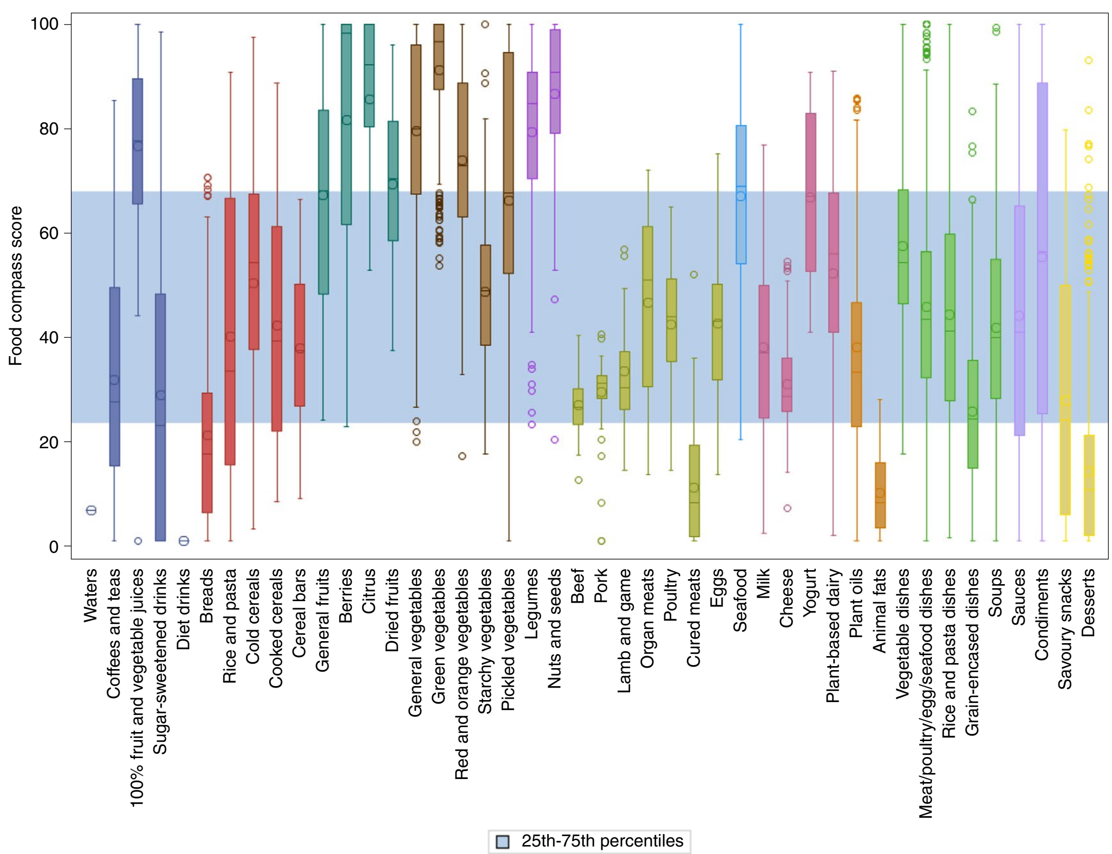


Fig. 2 | FCS for 8,032 unique foods and beverages consumed by US adults, based on NHANES 2015–16. Foods and beverages are grouped in 12 major food categories (top) and 44 food subcategories (bottom). Standard box plots are shown, with the open circles representing the mean score, the horizontal lines representing the median FCS, the shaded bars representing the interquartile range (25th to 75th percentiles), the error bars representing the 5th and 95th percentiles, and the small circles representing additional outliers. The shaded blue region represents the 25th and 75th percentile bounds for all 8,032 items.

Food Compass versus NOVA classification. The discriminant potential of the FCS was evaluated within each category of NOVA. The mean ± s.d. FCS was 65.5 ± 26.7 for NOVA = 1 (unprocessed, ~18.7% of all food items), 54.4 ± 24.6 for NOVA = 2 (culinary ingredients as well as mixed dishes with weighted NOVA score = 2, ~23.8%), 50.6 ± 25.0 for NOVA = 3 (processed as well as mixed

Table 2 | Correlations between FCS and other NPS

Food category	No. of items	FCS versus HSR	FCS versus Nutri-Score	HSR versus Nutri-Score
Beverages	275	0.38	0.27	0.73
Grains	727	0.25	0.17	0.89
Fruits	264	0.70	0.81	0.89
Vegetables	1,565	0.23	0.53	0.75
Legumes, nuts and seeds	264	0.45	0.27	0.75
Meat, poultry and eggs	763	0.59	0.72	0.88
Fish and seafood	434	0.41	0.41	0.75
Dairy	245	0.46	0.72	0.77
Fats and oils	129	0.49	0.36	0.71
Mixed dishes	2,206	0.62	0.60	0.84
Sauces and condiments	160	0.62	0.60	0.88
Savoury snacks and sweet desserts	1,000	0.40	0.25	0.89
Overall	8,032	0.70	0.66	0.87

The HSR and the Nutri-Score first generate a numerical score, which is then used to classify a product into a category. These numerical scores were used to assess Spearman correlations (values shown) between the various NPS. For the Nutri-Score, lower scores are considered healthier, and thus correlations were evaluated for the inverse of the Nutri-Score.

dishes with weighted NOVA score = 3, ~21.9%) and 27.8 ± 23.7 for NOVA = 4 (ultraprocessed, ~35.6%). Within each NOVA category, food items had relatively broad ranges of scores (Supplementary Fig. 3). Among all items, 53.1%, 72.3%, 75.1% and 93.4% of products had FCS < 70 in NOVA categories 1, 2, 3 and 4, respectively.

The discriminant ability of the Food Compass versus NOVA can be compared by reviewing all 8,032 food items (Supplementary Table 7). For instance, within NOVA = 1, the FCS was 100 each for raw raspberries, 79 for raw banana, 73 for raw fig, 65 for 100% apple juice, 48 for whole boiled egg and 46 for whole milk. Within NOVA = 2, the FCS was 81 for olive oil, 17 for lard, 6 for unsalted butter and 1 for white granulated sugar. Within NOVA = 3 (processed), food items with FCS > 70 included fresh, frozen and canned cooked asparagus (100), canned oysters (94), salted mixed nuts (92), and smoked salmon (83). And, within this same category, reduced sodium Swiss chess had FCS of 54, fried pork chops scored 30, low-sodium bacon scored 29 and plain cooked couscous scored 11. The Food Compass was especially discriminatory in NOVA = 4, where 60.8% of items had FCS ≤ 30 (foods to be minimized), 32.6% had FCS = 31–69 (foods to be consumed in moderation) and 6.6% had FCS > 70. For example, concordance with NOVA = 4 was seen for many candies, white bread, hot dogs and soft drinks (FCS ≤ 30). Yet, even within this range, certain foods had higher scores—for example, canned yellow corn creamed style, cream of wheat with non-dairy milk, frozen packaged cooked corn with butter, pumpkin pie, baked batter-dipped onion rings from fresh and peach nectar (all 20–29). Many foods in NOVA = 4 had an intermediate FCS (~40–65), such as broiled coated catfish, creamed frozen Brussels sprouts, Kellogg's Nutri-Grain Cereal Bar and Post Grape-Nuts and several microwave popcorns, while a few foods had a high FCS (≥70), including certain packaged spaghetti sauces, ready-to-heat whole grain pasta with tomato sauce and seafood, and certain whole grain, high-fibre breakfast cereals.

Food Compass versus the HSR and the Nutri-Score. We compared the Food Compass with the HSR (a continuous score used to create 10 rating categories, ranging from half a star to five stars), and the overall correlation was moderate (Spearman's $r = 0.70$) (Table 2). In other words, the HSR explained only ~49% (0.70 × 0.70) of the variation described by the FCS. This correlation varied widely by food category: it was the highest for fruits ($r = 0.70$) and mixed dishes (r=0.62), and much lower for others, for example legumes, nuts and seeds (r=0.45), fats and oils (r=0.49), dairy (0.46), fish and seafood (r=0.41), savour snacks and sweet desserts (r=0.40), grains (r=0.25), and vegetables (r=0.23). The findings were generally similar when comparing the Food Compass with the Nutri-Score, with modest overall correlation ($r = 0.66$ (~45% of variation explained)) and low correlations in many major categories (for example, fish and seafood, 0.41; fats and oils, 0.36; legumes, nuts and seeds, 0.27; savoury snacks and sweet desserts, 0.25; and grains, 0.17). In contrast, the HSR and the Nutri-Score were very similar to each other in scoring, both overall and across food categories, with many correlations approaching 0.90.

Convergence and concordance between the FCS and the HSR or Nutri-Score were reasonable in food categories where correlations were higher, but poor in other categories (Figs. 3 and 4). While the FCS tended to rise with the HSR or Nutri-Score overall, a wide range of FCS variation was evident within any HSR or Nutri-Score category, especially for certain food groups, where the FCS produced notably different scores.

A comparison of concordance and discriminant ability of the FCS versus the HSR, the Nutri-Score and NOVA for all 8,032 foods and beverages is shown in Supplementary Table 7. For example, many dairy foods scored similarly on the FCS and the HSR, although low-fat milks often scored very highly on the HSR (4.5–5 stars) but moderately on the FCS (~49 to 63). Within grains, whole grains (breads and cereals) generally scored high on both the FCS and the HSR, but many refined grains scored much higher on the HSR than the FCS. For example, most white bread, rolls, buns, breadsticks and plain white rice had HSR scores of 3.5–4.0 stars but FCS of 12 or less. Legumes, nuts and seeds scored highly on both the FCS and the HSR when consumed by themselves, but many mixed dishes adding pork, beef or processed meats continued to score very highly on the HSR (4.5 to 5 stars) but moderately on the FCS (60s or lower). Within meat, poultry and egg dishes, many items scored moderately on both the FCS and the HSR, while many processed meats (for example, hot dog, sausage and bologna) scored low on both. However, several reduced-fat processed meat items (for example, processed ham or chicken luncheon meat and reduced-fat hot dog) scored fairly well on the HSR (3 to 4 stars) but low on the FCS (<20). Among fats and oils, olive, sesame and peanut oils received an FCS in the 70s-80s but an HSR of only 3; conversely, many fat-free salad dressings and fat-free coffee creamers (largely made of starch, sugar, salt and stabilizers) received a favourable HSR (~3.5) but a very low FCS (≤30).

Comparing the FCS and the Nutri-Score, many 100% juices and fruit and vegetable smoothies scored highly on the FCS (>70) but moderately or poorly on the Nutri-Score (C or D) (Supplementary Table 7). In contrast, pre-sweetened coffees, energy drinks and fruit drinks scored moderately on the Nutri-Score (C or D) but very low on the FCS (<10). Nearly all breads, rices and cooked cereals scored very highly on the Nutri-Score (A or B) but more moderately or even low on the FCS. Similar differences were seen for canned and cooked starchy vegetables (such as peas and corn). The FCS and Nutri-Score ratings for meats, poultry and eggs were generally comparable. For fish and seafood, added salt (for example, smoking) or fat during cooking often lowered the Nutri-Score grading to a C or D category but had much smaller effects on the FCS. Fats and oils showed striking differences, with low Nutri-Scores (C or D) for all plant oils, including olive, walnut, almond, soybean, canola, rapeseed, safflower, sunflower and peanut oils (all FCS > 70), and virtually no differentiation by the Nutri-Score between those plant oils and tub margarines, cream, butter, lard or fat-free (oil-free) salad dressing.

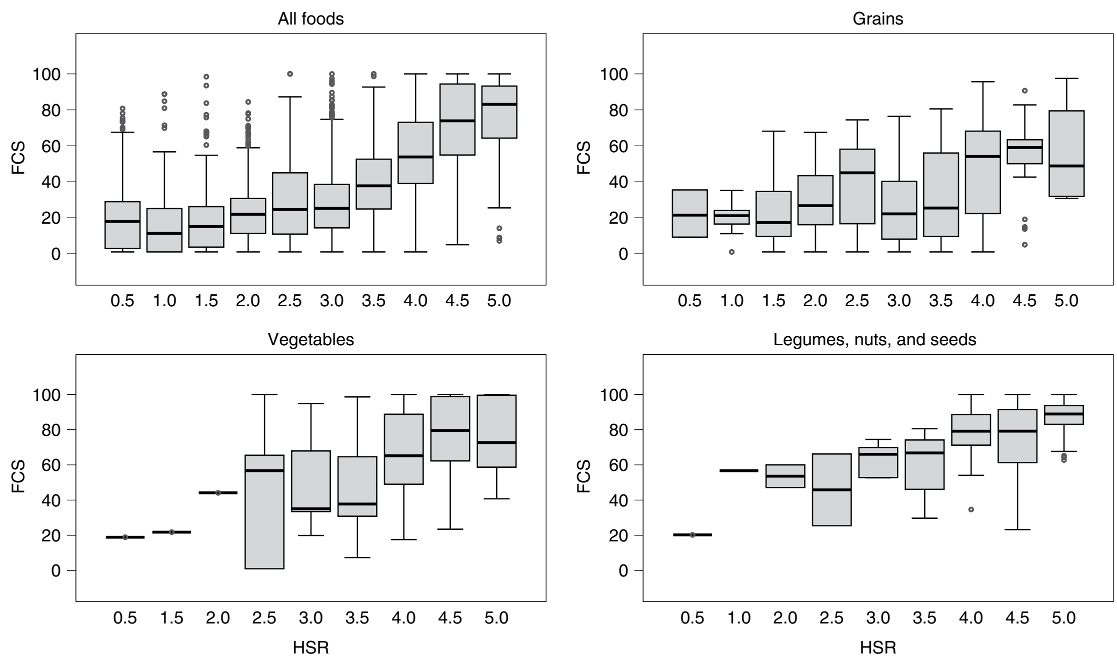


Fig. 3 | FCS according to HSR category for 8,032 unique foods and beverages consumed in the United States (NHANES/FNDDS 2015–16). Box plot distributions are shown for all foods (top left), grains (top right), vegetables (bottom left), and legumes, nuts and seeds (bottom right). The horizontal lines (and values) represent the median FCS, the shaded bars represent the interquartile range (25th to 75th percentiles), the error bars represent the 5th and 95th percentiles, and the small circles represent additional outliers.

Discussion

Our findings indicate that the Food Compass is a credible, transparent tool for science-based assessment of the overall healthfulness of diverse foods, snacks, beverages and mixed dishes. Several features are notable. The FCS emphasizes both adverse characteristics and beneficial attributes—that is, credit for increasing the good. It incorporates not only macronutrients, vitamins and minerals but also multiple health-related food ingredients, phytochemical contents, specific lipids and processing features. The FCS utilizes updated evidence for the health effects of both established and emerging factors. For example, total fat is common in other NPS but excluded from the FCS on the basis of evidence for minimal health effects, saturated fat is not assessed in isolation but as part of overall fat quality, potassium and sodium integrate their biologic interaction, and phytochemicals are considered[23]. The use of distinct scoring domains facilitates joint consideration of different aspects of foods while also preventing undue influence of any one attribute or domain. The scoring of attributes per 100 kcal provides a more comparable assessment across foods and beverages than by weight (confounded by water) or serving size (highly variable across items). Finally, the Food Compass scores all items uniformly using the same attributes, domains, algorithm and cut-off points.

These features contrast with existing NPS[3–5,9,11,15–17], which often assess few attributes, prioritize harmful factors, omit many food characteristics and use inconsistent scoring across arbitrary food categories. The HSR, for instance, has six different food group scoring algorithms, while the Nutri-Score has four, to help their scores match external evidence on health effects and dietary guidance. Beyond the hazards of subjectivity, inconsistency and industry lobbying for each category's algorithm (already happening for the HSR), variable treatment of different food groups creates anomalies for assessing foods with mixed ingredients. In the HSR, for example, not only do milk and yogurt, fats and oils, cheese, and grains each have separate scoring algorithms when packaged separately, but a mixed food containing more than one of these must be classified and scored on the basis of selecting only one of these algorithms, crafted to assess only one of these components. In addition, most existing NPS have not undergone any type of validation[3,4].

The FCS, with strengths of objectivity, diverse health-relevant attributes, universality of scoring and additive discriminatory ability, has corollary limitations in its parsimony and ease of scoring. Its comprehensive nature could thus limit applicability in certain contexts, such as when product data are more limited. Such challenges could be partly addressed by leveraging the 8,000+ scored food items in NHANES and imputing missing attributes in other datasets by using averages or weighted averages of similar products. In future work, online applications could also allow consumers and companies to enter products, using public nutrient information or UPC codes, to be matched against existing product datasets and generate an automated FCS. Because we have transparently published the mathematical algorithm in the current report, additional scientific groups can develop other approaches for applying the FCS. The limitation is not the current science or practical ability to measure any of these attributes but the current absence of meaningful motivation for the broader food industry to measure and report on all of them. Such characteristics could be readily calculated and provided by food manufacturers and restaurants if they were provided the incentive to do so.

When comparing the Food Compass with NOVA, unprocessed items (NOVA = 1) generally scored as healthier (mean FCS, ~63) than ultraprocessed items (NOVA = 4; mean FCS, ~25), and the Food Compass also classified processed foods (NOVA = 3; mean FCS, ~50) as closer to unprocessed items. These findings are consistent with observational associations with health risk factors and endpoints suggesting that most of NOVA's discrimination occurs between categories 1 and 4, and not 2 or 3 (refs. [10,24]). More importantly, the Food Compass displayed further discrimination within each NOVA category, such as comparing whole fruits, whole eggs and milk in NOVA = 1; olive oil, lard and granulated sugar in NOVA = 2; and canned vegetables, salted nuts, cheese, bacon and white rice in NOVA = 3. Notable disrimiation by the Food Compass occured within NOVA = 4 (about one-third of all

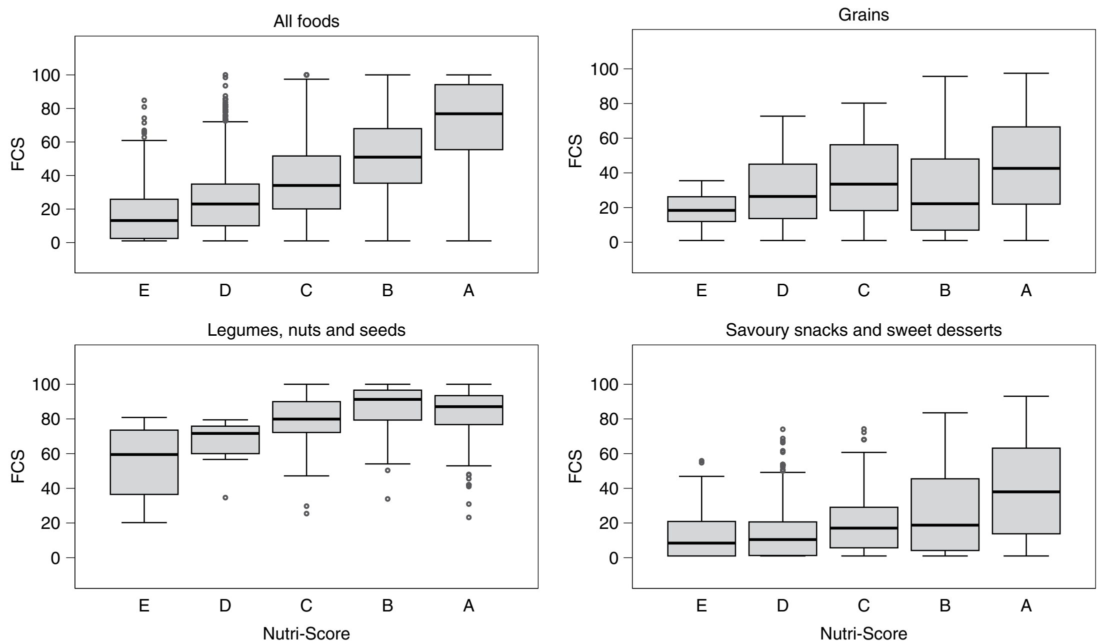


Fig. 4 | FCS according to Nutri-Score category for 8,032 unique foods and beverages consumed in the United States (NHANES/FNDDS 2015–16). Box plot distributions are shown for all foods (top left), grains (top right), legumes, nuts and seeds (bottom left), and savoury snacks and sweet desserts (bottom right). The horizontal lines (and values) represent the median FCS, the shaded bars represent the interquartile range (25th to 75th percentiles), the error bars represent the 5th and 95th percentiles, and the small circles represent additional outliers. The continuous Nutri-Score is converted to five categories, with different cut-off points for four different food groups for each of these categories; category A is considered the healthiest, and category E is considered the least healthy.

items in NHANES), where ~61% of foods had FCS ≤ 30, but ~32% had FCS = 31-60 and had FCS = 31–69 and ~7% had FCS > 70. Review of these 'ultraprocessed' foods with low, intermediate and high scores suggested concordance of the FCS with dietary guidance, nutritional qualities and health associations of these food items.

The HSR has been applied in government-sanctioned voluntary FOP labelling in Australia and New Zealand and in the Access to Nutrition Index ratings of major multinational food companies. The Nutri-Score has similarly been adopted in several European nations and is being considered for broader use across the European Union. The HSR and the Nutri-Score were designed for packaged foods, not home-cooked foods, restaurant meals or mixed meals including multiple items, and thus the comparison with the FCS (which can be used for these purposes) should be interpreted in that context. Conversely, validation of these scores against health outcomes has necessarily assessed all foods and beverages as consumed[25–31]. The very high correlations between the HSR and the Nutri-Score (often approaching $r = 0.90$) indicate that these two systems provide very similar information on foods. In contrast, the FCS only moderately correlated with these other NPS overall, and much less for categories such as grains; fats and oils; fish and seafood; beverages; vegetables; legumes, nuts and seeds; and savoury snacks and sweet desserts. Compared with the FCS, the Nutri-Score often scored 100% juices much lower and pre-sweetened coffees, energy drinks and fruit drinks much higher. Both the Nutri-Score and the HSR often gave healthier scores than the FCS to processed foods rich in refined grains and starch, and much lower scores than the FCS to foods rich in healthful unsaturated plant oils. The HSR also often gave healthier scores than the FCS to low-fat dairy and low-fat processed meats. These results suggest that, particularly for certain major food categories, the Food Compass may better reflect current evidence on health harms of processed refined grains and low-fat processed meats, the health benefits of unsaturated fats from plant sources, and the minor health relevance of total fat. These observed advantages are consistent with a 2019 government-solicited review of the older (pre-2020) HSR, which identified over-scoring by the HSR of breakfast cereals, snack bars, sweetened milks and sugar-based confectionary, and under-scoring of healthier oils and oil-based spreads[32]. These problems led to 2020 updates in the HSR algorithm; but even when using this new HSR algorithm, our analyses identified persistent similar challenges.

Potential limitations should be considered. Some Food Compass attributes with known health effects, such as iodine and trans fats, were unavailable in FNDDS. However, because domain scoring prevents major influence of any single attribute, their addition from other data sources should further improve validity and discrimination but would probably not greatly alter any single item's FCS. The potential differential scoring of naturally occurring versus fortified vitamins, minerals, trace lipids or fibres requires further study, when feasible based on both scientific information on potential differential health effects and available food databases. We elected to include, with reduced scoring weights, attributes with emerging but not yet conclusive evidence for health effects—this values emerging science but could also increase controversy. Because domains, attributes and relative weights were identified on the basis of biologic and scientific considerations of major health endpoints, this aided objectivity but reduced ability to explore varying weighting schemes. Scores were derived per 100 kcal, requiring more study on how to score very low-calorie items (<5 kcal per 100 g), which could influence health directly (for example, coffee and tea) or displace (for example, diet drinks and water) other beverages. Finally, while the Food Compass was tested and validated against two major NPS and NOVA, next steps include testing against health outcomes, application to other product datasets and testing in other world regions with widely differing available food products.

The Food Compass is an NPS with attractive characteristics that can assess and compare the healthfulness of diverse foods and beverages and their combinations such as in a shopping basket, diet pattern or company portfolio. The publicly available scoring algorithm can inform a more nuanced approach to help guide consumer behaviour, food policy, scientific research, industry reformulations and socially focused investment decisions.

Methods

The design and development of the Food Compass involved four main steps: (1) the assessment of existing NPS, dietary guidelines, health claims and diet–health relationships, (2) the selection of attributes, (3) the development of scoring principles and the scoring algorithm, and (4) testing and validation. As this study was performed using published reports as well as deidentified, publicly available data in NHANES, institutional review board approval was not required for this investigation.

Assessment of existing NPS, dietary guidance and diet–health relationships. To help inform the selection of attributes and scoring principles of the Food Compass, we assessed the current scientific landscape of major NPS and related FOP labels, as well as national and international dietary guidance. We found more than 100 reported NPS with certain similarities and many differences in components, scoring principles and thresholds, and design[4,9]. We reviewed the NPS characteristics, including the nutrients or other food attributes scored, whether positive and/or negative factors were considered, the scoring algorithm and whether the scoring varied for different food or beverage categories. From that evaluation, we focused on seven widely used NPS of diverse origins, used primarily for interpretative food/FOP labelling, that represent a variety of methodologies, organizations and country coverage—namely, Guiding Stars (United States), the Nutri-Score (Europe), the HSR (Australia and New Zealand), the Nordic Keyhole (Scandinavia), Singapore Healthy Choice (Singapore), Waqeya (United Arab Emirates) and the Nestle Nutrient Profiling System (Supplementary Table 1). The number of attributes considered in each NPS typically ranged from 7 to 12 (and also varied within some of these NPS depending on the food category). Most NPS counted macronutrients, vitamins and/or minerals; a few NPS also considered a limited number of ingredients, such as fruit, vegetable or legume content. For each of these seven NPS, different subgroups of foods (for example, milk, other beverages, grains and cheese) were scored using different attributes, methods and algorithms, ranging from 4 to 33 differentially scored food categories across these NPS.

For guidelines and official recommendations, we used a recent systematic review of about 90 national and international dietary guidelines[2]. In contrast to the nutrient focus of most NPS, this analysis identified most dietary guidelines to be food-focused. All encouraged certain beneficial food groups, such as vegetables, fruits and whole grains; and most provided guidance on other food groups to help achieve certain nutrient targets, such as consuming dairy foods to achieve calcium and vitamin D targets. Most guidelines also provided information on a selected number of nutrients to limit, primarily sodium, added sugar and saturated fats, and some extended these to specific foods, such as the reduction of red and processed meats. Brazil's guidelines emphasized food processing characteristics. The World Health Organization offered generalized dietary recommendations aimed at the prevention of malnutrition, as well as limiting certain nutrients linked to non-communicable diet-related diseases such as sodium and added sugar.

We also assessed the US Food and Drug Administration nutrient content requirements for health claims, including for general health claims; for claiming 'good source', 'high', 'more', and 'high potency'; for claiming 'light' or 'lite'; and for using the term 'healthy' or related terms (Supplementary Table 2). Building on these evaluations of NPS, dietary guidelines and health claims, we assessed which nutrients, ingredients and other food characteristics were linked to health outcomes in observational studies or randomized trials, have been prioritized in population diet pattern scores, or were of emerging public health interest[18–21].

Selection of attributes. On the basis of the assessments above, we selected key nutrients, ingredients and other food characteristics for inclusion. We did not make any assumptions about a desirable number of attributes. Rather, we aimed to address gaps in existing NPS by developing a more updated, more discriminatory NPS that incorporated key new attributes likely to be related to health, that excluded outdated nutrients for which modern evidence suggests little impact on major health endpoints and that allowed for universal scoring of all foods and beverages, including mixed dishes, using the same algorithm and scoring thresholds. We prioritized attributes related to risk of major chronic diseases such as obesity, diabetes, cardiovascular diseases and cancers, and to risk of major undernutrition outcomes, especially for maternal and child health and the elderly. We further considered food characteristics with more recent evidence for important health impacts, such as processing characteristics and presence of phytochemicals (carotenoids and flavonoids), and characteristics with emerging evidence for potential benefits (for example, fermentation) or harms (for example, preservatives). The final selections were guided by discussions and consensus among all investigators.

We considered several standards for assessing each attribute, including content per 100 kcal, per 100 g, per litre and per serving size[4]. Contents per 100 g, commonly used for many other NPS, are strongly confounded by water weight—for example, when comparing raw versus cooked spinach. Contents measured by volume, such as cups or litres, are confounded by differing contents of air, water, dietary fibre and fat, such as when comparing a high-bulk breakfast cereal versus muesli or granola. These differences are also important when comparing grains and other starchy staples. For example, a half cup of cooked rice (~141 kcal) weighs 93 g, whereas two slices of white bread (~158 kcal) weigh 60 g. Among discretionary foods, 150 kcal of soda weighs 245 g (8 fl oz), while 150 kcal of fruit-flavoured candy weighs 37.5 g (1.3 oz). On the basis of these considerations, we selected assessment of all foods and beverages per 100 kcal (418.4 kJ) to facilitate the use of a single scoring algorithm for a diverse range of items, from a single small item to a food with mixed ingredients or a large mixed dish or meal, even among items that differ greatly in bulk. Scoring per 100 kcal was also considered valuable for scaling up to compare diverse combinations that may be sold and consumed together—for example, to score an entire shopping basket, an entire diet or an entire portfolio of foods being sold by a particular vendor.

Additional relevant attributes. Several other relevant attributes were considered but not included due to more limited available scientific information on their health impacts and/or contents in major food and beverage databases. For example, we considered separately scoring naturally occurring versus fortified vitamins, minerals and fibre. However, most food databases do not provide separate information on such contents, nor is the science clear that the health impacts of many naturally occurring versus fortified compounds differ. Instead, the use of Dietary Reference Intakes (DRIs) and percentile ranges in the Food Compass buffered potential extremes in maximum values of nutrients (for example, vitamin C) that may be fortified at high levels. In the 'Processing' domain, the extent of heating or cooking (for example, the charring of meat), milling of grains or other measures of food structure were considered, but reliable information on these characteristics was considered to be still lacking in most large food databases. Also, the development of the Food Compass was based on the current best evidence regarding dietary factors and their links to cardiometabolic diseases, cancers and a variety of conditions associated with undernutrition. However, the Food Compass was designed so that additional attributes and scoring could evolve on the basis of future evidence, including other outcomes such as gut health, immune function, brain health, bone health, sarcopenia and degrees of physical and mental performance.

Scoring principles and algorithm. Attributes could be scored in four ways. Most were scored on the basis of a linear 10-point scale from 0 to 10 for attributes considered to have a positive overall health impact and from −10 to 0 for attributes considered to have an adverse overall health impact (Supplementary Table 3). For attributes with a defined DRI, such as vitamins and minerals, the target level (maximum points) was set at 25% of the adult DRI value for a 2,000-kcal-per-day diet, which most consistently distinguished foods and beverages with higher versus lower levels of these nutrients and was generally similar to the 95% percentile value of content across all foods and beverages reported in NHANES 2015–16. For attributes without DRIs, the target level was set on the basis of the 95th percentile value of foods and beverages consumed by the US population (based on 2015–16 NHANES data). For attributes that were ratios of positive versus adverse factors (for example, the ratio of unsaturated to saturated fat), scoring was on a log-linear scale from −10 to 10 points to represent the full range of the ratio, with reference targets for the lowest and highest points based on the 5th and 95th percentile values of foods consumed by the US population. For attributes for which information was generally binary (for example, the presence or absence of preservatives; artificial sweeteners, flavours or colours; fermentation; or frying), scoring was binary (−10, 0), with half-weights for most of these factors based on still emerging evidence for health impacts. The attribute based on NOVA processing was scored categorically ranging from −10 to 0.

To prevent any single attribute from dominating a food's score and to provide a more holistic assessment of overall health impact, the identified relevant attributes were grouped into nine domains that represented different health-relevant aspects of foods: major nutrients, vitamins, minerals, food ingredients and so on. Each domain's score was calculated as the average of its attribute scores (or for food ingredients, the sum), and then the domain scores were summed to calculate the summary score for each food. The same scoring principles and algorithm were used for all foods and beverages.

Testing and validation. For testing and validation, the Food Compass was applied to all foods and beverages reported in NHANES 2015–16, utilizing FNDDS 2015–2016, with information from the Food Pattern Equivalents Database 2015–2016 and the 2010 US Department of Agriculture Flavonoid database. The scored foods and beverages were those reported as consumed by children and adults ($N=8{,}032$ products), in their form as consumed. We excluded infant formula, baby foods, specialized dietary foods (such as nutritional supplements for athletic performance or treatment for health conditions), alcohol, and beverages providing <5 kcal per 100 g (for example, unsweetened tea or coffee and diet soda). See Supplementary Text 1 for details on scoring the Food Compass in NHANES.

The final score distributions were calculated overall and stratified into 12 major food groups and 44 food subgroups, determined on the basis of the US Department of Agriculture's What We Eat in America[33], the European Food Safety Authority's FoodEx2 (ref. [34]), the George Institute's *FoodSwitch: State of the Food Supply* report[35], the United Nations Classification of Individual Consumption According to Purpose[36] and alignment to evidence on key diet–disease relationships[18,37].

The Food Compass was explicitly developed for content validity—the inclusion of nutrients, food ingredients and other dietary characteristics of public health concern. We further assessed face validity by evaluating FCS values across FNDDS food categories and subcategories, considering both the distributions of the scores and the specific examples of foods scoring higher, middle and lower in each category. We assessed convergent and discriminant validity by comparing the Food Compass with the NOVA classification (an increasingly used classification system based on processing) and with the HSR (using the updated 2020 algorithm) and the Nutri-Score, among the most detailed existing NPS and each increasingly used both for national consumer guidance and for assessing food manufacturer performance to promote reformulations[38,39].

Data availability

The attribute and domain scoring algorithm used to generate the Food Compass is available in the Supplementary Information. The NHANES data are publicly available at https://www.cdc.gov/nchs/data_access/ftp_data.html. The statistical coding is not available. The generated Food Compass, HSR and NOVA food processing classification scores for each of the 8,032 food items in the dataset are available in the Supplementary Information.

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Author contributions

D.M., N.H.E.-A., W.A.M., P.J., J.B.B. and R.M. conceived and designed the work. D.M. and N.H.E.-A. acquired the data. N.H.E.-A., M.O., J.E.-M. and P.S. analysed the data. All authors interpreted the data. D.M. drafted the manuscript, and all authors substantively revised the manuscript. In addition, all authors approved the submitted version and have agreed both to be personally accountable for their own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated and resolved and the resolution documented in the literature.

Competing interests

D.M. receives personal fees from Acasti Pharma, Barilla, Cleveland Clinic Foundation, Danone and Motif FoodWorks; is on the scientific advisory boards of Brightseed, Calibrate, DayTwo (ended June 2020), Elysium Health, Filtricine, Foodome, HumanCo, January Inc., Perfect Day, Season and Tiny Organics; and receives chapter royalties from UpToDate. J.B.B. reports personal fees from Guiding Stars Licensing Company. All other authors declare no competing interests.

Additional information

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