

# Nutritional Value Score rates foods based on global health priorities

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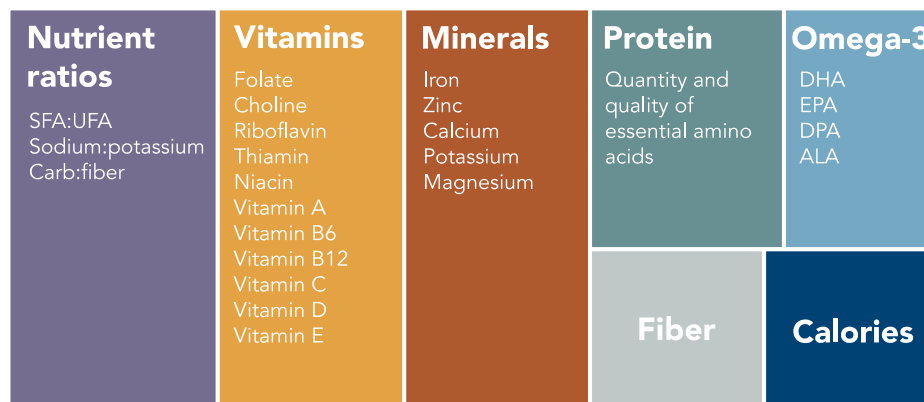
## Abstract

Nutrient profiling systems (NPS) are used to rate foods by nutritional value using food composition data. NPS have different purposes and limitations. Existing systems have not adequately addressed Calorie and nutrient density and nutrient bioavailability. Recent publications have also called for developing NPS for global use and for assessing environmental impacts and affordability of foods. To address these needs, we developed the Nutritional Value Score (NVS), which is based on nutrients of global health priority and nutrient ratios predictive of noncommunicable disease risk. The NVS adjusts for nutrient bioavailability and quantifies nutrient density in terms of Calories *and* grams, to address limitations in existing systems. Using common foods from Indonesia and Bangladesh, the NVS effectively highlights nutritious items within recommended food groups. It also enables more nutritionally equivalent comparisons in environmental impact and affordability assessments. Although further validation is needed, initial testing suggests the NVS is a flexible tool that can be tailored to identify healthy and sustainable foods in different contexts.

Nutrient profiling systems use food composition data to estimate nutritional value or healthfulness<sup>1-3</sup>. They are typically used to guide consumer choice, food policy, industry formulations, and investments. Popular implementations of nutrient profiling systems, including Nutri-Score in the European Union and Health Star Rating in Australia and New Zealand, were developed for front-of-package labelling in high-income countries with the primary objective to reduce noncommunicable disease risk, but they omit density in essential micronutrients. Others like Food Compass<sup>3</sup> and the Nutrient Rich Foods index<sup>4</sup> have been developed using data from high-income countries but aim to better capture risk for noncommunicable diseases *and* essential nutrient density. Each existing nutrient profiling system has strengths and limitations and is suitable for different purposes.

Food Compass<sup>3</sup> has notable strengths, including incorporating a wide range of dietary attributes reflective of healthfulness, like nutrient ratios, and validating against measures of diet quality, cardiovascular disease, and mortality<sup>5</sup>. The Nutrient Rich Foods index<sup>4</sup> has unique strengths, like excluding nutrients without public health relevance and offering adaptations for different uses, as well as validating against diet quality measures. However, both Food Compass and the Nutrient Rich Foods index only evaluate nutrient density per Calorie, which may underestimate the value of nutritious but energy-dense foods. Neither system accounts for differences in bioavailability of key nutrients like iron, zinc, and essential amino acids<sup>6</sup>. Food Compass uniquely includes some nutrients like phosphorus<sup>7</sup> and dietary cholesterol<sup>8</sup> that have limited public health relevance. The Nutrient Rich Foods index distinctly estimates noncommunicable disease risk using limiting nutrients, rather than nutrient ratios, which evidence suggests may better predict disease risk<sup>3</sup>.

48 We developed a Nutritional Value Score (NVS) based on global health priorities to  
49 discriminate the nutritional value of foods recommended in global dietary guidelines for  
50 evidence-based policy and programming in low- and middle-income countries<sup>9</sup>. We excluded  
51 fortified foods, due to a scarcity of reliable local food composition data, and ultraprocessed  
52 foods, because they are typically not the focus in dietary guidelines globally. The NVS  
53 assesses the quantity and quality of essential nutrients as well as other dietary attributes that  
54 indicate protection against noncommunicable diseases. It is based on seven components:  
55 nutrient ratios, vitamins, minerals, essential amino acids, *n*-3 fatty acids, fiber, and Calories  
56 (Fig. 1). We also produced a Nutrient Density Score based solely on the four essential  
57 nutrient components, which can be used to identify nutrient dense foods to be targeted in  
58 policies and programs seeking to address essential nutrient deficiencies and associated  
59 undernutrition. The NVS and each component score, except for the Calories score, is scaled  
60 from 1 to 100, where 1 is the food with the lowest nutritional value and 100 is the food with  
61 the highest. The Calories score is scaled from –100 to 0, where –100 is the lowest score and 0  
62 is the highest score. The NVS is intended to inform evidence-based policies and programs. It  
63 is also designed specifically for use in environmental impact and affordability assessments,  
64 which have difficulty incorporating nutritional differences in foods using common units like  
65 1 kg or 1,000 Calories.



**Fig. 1 | Nutritional Value Score components.** The area of the boxes indicates the weights of each component in the algorithm.

The NVS follows the latest scientific guidance on developing nutrient profiling systems for global use<sup>2</sup>, food sustainability assessments<sup>10</sup>, and affordability assessments<sup>11</sup>. The NVS also has unique features. It solely includes essential nutrients of global health priority, omitting nutrients of little public health significance like phosphorus. Additionally, it adjusts for bioavailability of iron and zinc and measures the quantity *and* quality of essential amino acids, which vary considerably across foods. Moreover, the NVS quantifies nutrient density per unit mass *and* energy to account for the limitations in either approach when used in isolation (Supplementary Table 10, Supplementary Figs. 16 and 17). Further, it includes sub-scores for each nutritional component so that researchers, program managers, food producers, and policy makers can prioritize foods based on nutritional components of interest, making the NVS a flexible tool applicable across diverse contexts globally. While nutrient profiling systems have historically been focused on high-income countries, we developed the NVS using local foods from two low- and middle-income countries, to ensure global relevance. Notably, the NVS was developed without industry funding, to minimize private sector influence and bias. And finally, all methods, data, and code are published open access so that other researchers can easily use, validate, and adapt the approach in other settings.

86

## 87 **Results**

### 88 **Component nutritional scores**

89 We confirmed content validity of the NVS algorithm by aligning its components and weights  
90 with global health priorities in the scientific literature, expert peer feedback, and sensitivity  
91 analyses using different component weights (Supplementary Table 7). We tested face validity  
92 by applying the NVS algorithm to 127 unique Indonesian and Bangladeshi foods from  
93 country-adapted Diet Quality Questionnaires (dietquality.org) and analyzing each sub-score  
94 and final NVS across foods classified into five broad food groups recommended in global  
95 dietary guidelines: 38 vegetables, 29 animal source foods, 27 fruits, 19 starchy staples, and  
96 14 legumes, nuts, and seeds. We also confirmed the face validity of the NVS for food sub-  
97 groups in the Diet Quality Questionnaire. Both Indonesia and Bangladesh face a double  
98 burden of undernutrition and noncommunicable diseases. In the main text we present the  
99 results primarily for Indonesia, given the diversity of foods across and within food groups.  
100 Results for Bangladesh specifically are available in the Supplementary Material.

101

102 No food scores high in all components. For example, in Indonesia spinach has the top mineral  
103 score (90) yet an *n-3* score of just 15, while chicken organs have the top vitamin score (92)  
104 yet fiber and *n-3* scores of just 1 (Table 1). Foods with the highest vitamin scores are chicken  
105 organs, beef organs, and dark green leafy vegetables like spinach and moringa leaves, while  
106 foods with the lowest vitamin scores include certain starchy staples like white rice noodles  
107 and refined wheat pasta, fruits like coconut and watermelon, and certain legumes like oncom  
108 and tofu. Mineral scores are highest for dark green leafy vegetables like spinach and pumpkin  
109 leaves, chicken organs, and nuts and seeds like cashews and sunflower seeds, but are lowest  
110 for certain starchy staples like white rice noodles and white rice, fruits like watermelon and

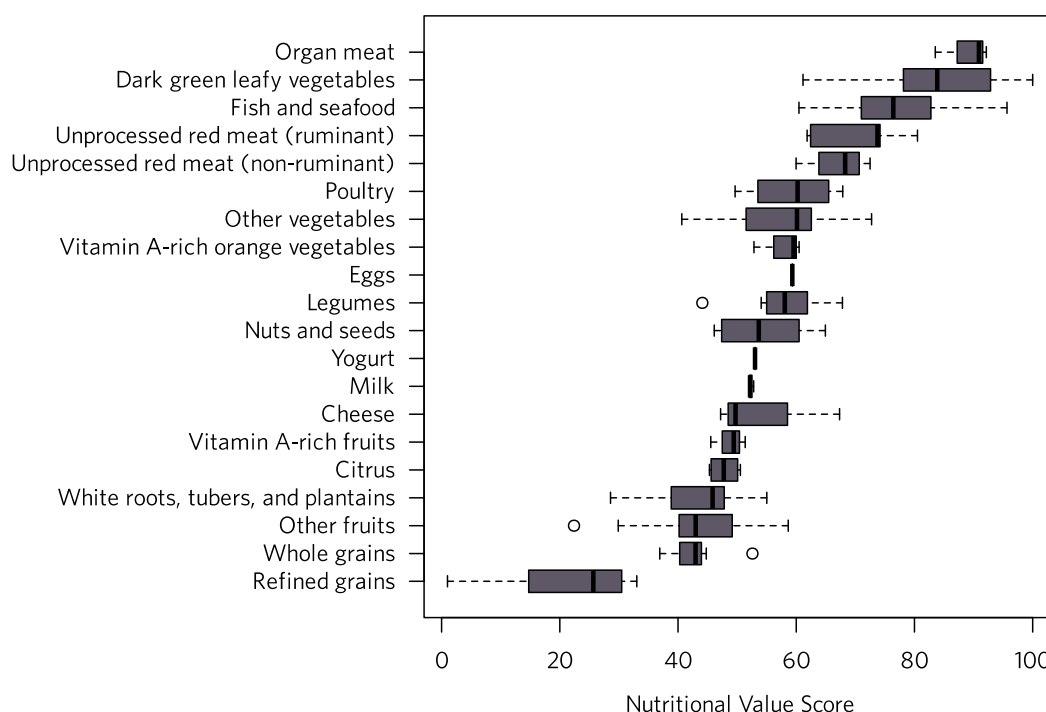
apple, and certain vegetables like tree fern and eggplant. Lean meats like boar and rabbit have the highest essential amino acids scores followed by other animal source foods and, to a lesser extent, soy products like tempeh, whereas starchy staples like cassava and sweet corn have the lowest essential amino acids scores followed by fruits like apple and pear. Lastly, fatty fish, bivalves, and crustaceans are the only high scoring foods in terms of *n*-3 content. Foods with the highest overall Nutrient Density Scores are organ meats, dark green leafy vegetables, and certain lean animal flesh foods like deer and bivalves, while the foods with the lowest Nutrient Density Scores are primarily starchy staples and fruits.

For fiber, the food with the top score is pumpkin leaves followed by beans and seeds like mung beans and sunflower seeds, while the lowest fiber scores are attributed to animal source foods, congee, certain fruits like watermelon and snake fruit, as well as oncom and soy milk. For Calories, the food with the lowest score is peanut butter, while most foods received the top score since they fell below the Calorie density cutoff of 1.3 Calories/gram. Similarly, most foods score highly on nutrient ratios since they are all foods recommended in dietary guidelines, excluding ultraprocessed foods, which tend to score poorly on nutrient ratios. The lowest scoring food by far is congee followed, to a much lesser extent, by coconut, white rice, snake fruit, oncom, and full-fat cheese.

### **Nutritional Value Scores**

The NVS can be used to compare the nutritional value of food groups and single foods, and it can be calculated for total diets. Aggregating across recommended food groups in the Diet Quality Questionnaires in Indonesia and Bangladesh, the highest scoring food groups (NVS > 75) are organ meat, dark green leafy vegetables, and fish and seafood (Fig. 2). Moderately high scoring food groups (NVS 50–75) include unprocessed red meat, poultry, other

vegetables, vitamin A-rich vegetables, eggs, legumes, nuts, seeds, and minimally processed dairy (Fig. 2). Moderately low scoring food groups (NVS 25–49) include whole grains, white roots, tubers, and plantains, other fruits, citrus, and vitamin A-rich fruits (Fig. 2). The lowest scoring food group (NVS < 25) is refined grains (Fig 2).

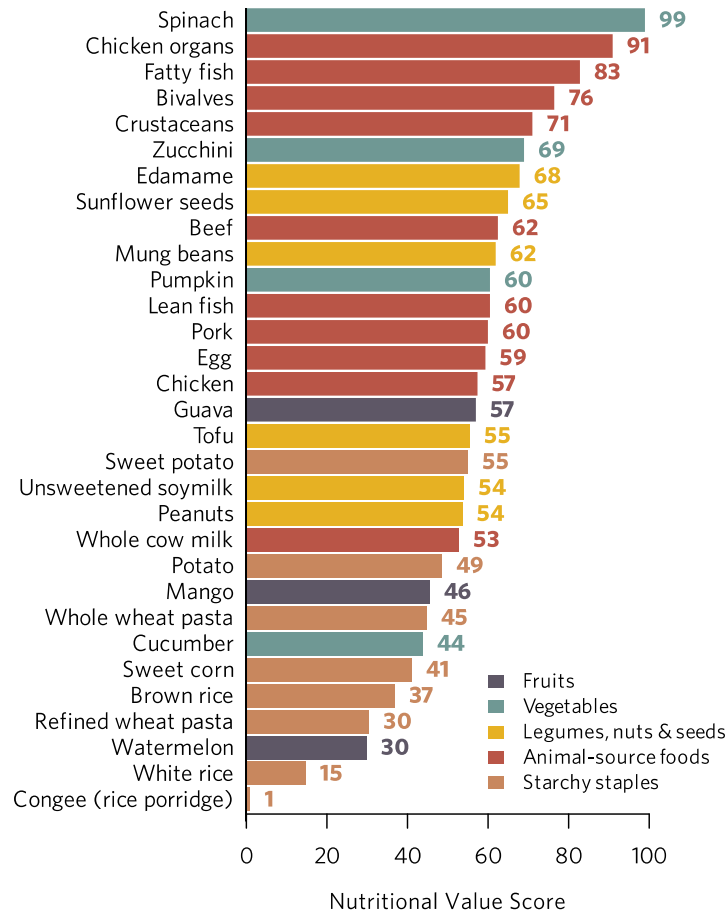


**Fig. 2 | Nutritional Value Scores for recommended food groups in the Diet Quality**

**Questionnaires in Indonesia and Bangladesh.** The Nutritional Value Score rates foods by nutritional value. It is scaled from 1 (lowest) to 100 (highest).

Across foods in Indonesia, the highest scores (NVS > 75) are seen for spinach and other dark green leafy vegetables, chicken and beef organs, fatty fish, deer, and bivalves (Table 1, Fig. 3). Moderately high scoring foods (NVS 50–75) include goat, crustaceans, zucchini, sunflower seeds, edamame, beef, lean fish, pork, eggs, pumpkin, mung beans, chicken, guava, sweet potato, unsweetened soymilk, cow milk, cantaloupe, and avocado, among others (Table 1, Fig. 3). Moderately low scoring foods (NVS 25–49) include cassava, watermelon, refined wheat pasta, brown rice, apple, eggplant, sweet corn, whole wheat noodles, banana,

and cucumber, among others (Table 1, Fig. 3). The lowest scores (NVS < 25) belong to congee, white rice, and coconut (Table 1, Fig. 3).



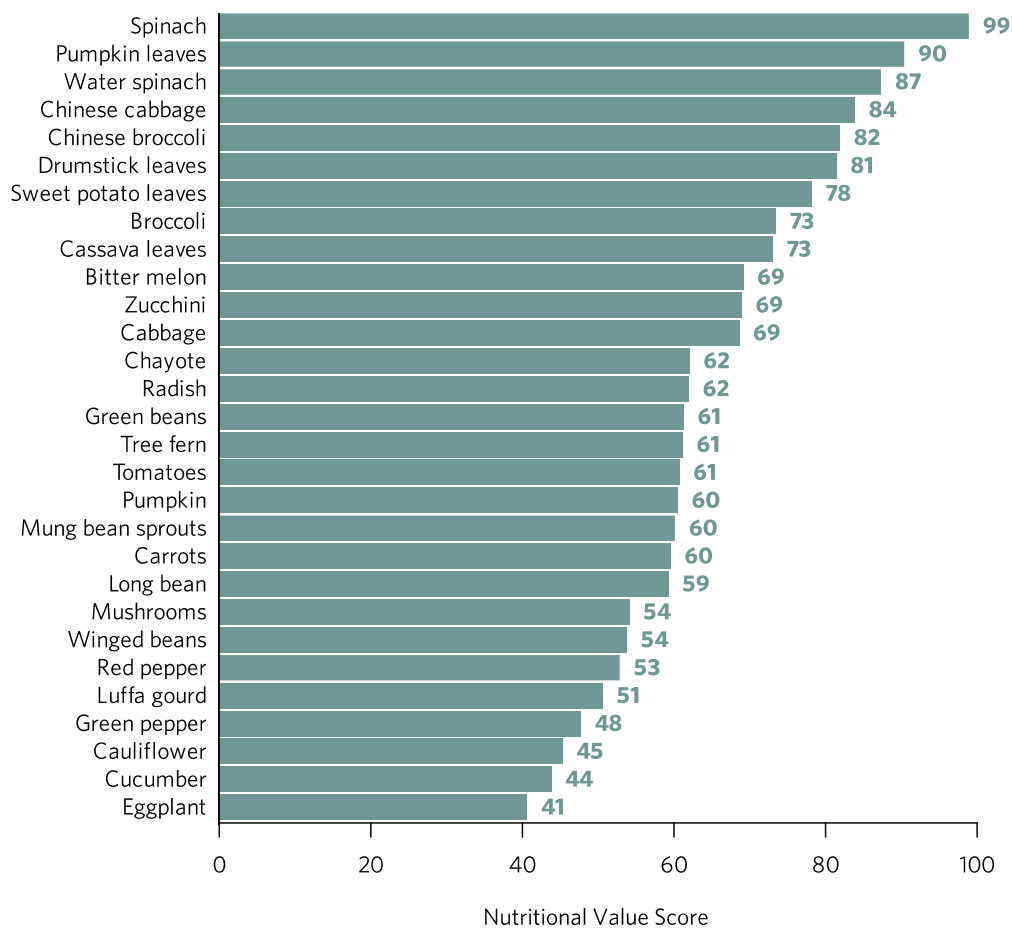
**Fig. 3 | Nutritional Value Scores for common Indonesian foods.**

The Nutritional Value Score rates foods by nutritional value. It is scaled from 1 (lowest) to 100 (highest).

The NVS also shows large variation between foods within the same broad food group. For vegetables, the NVS ranges from 41 to 99, with dark green leafy vegetables having the highest scores and eggplant, cucumber, cauliflower, and green pepper having the lowest scores (NVS < 50; Fig. 4). Most other vegetables fall in the middle, with a NVS typically between 50 and 70. Similarly, there is variation within the fruit category, with the NVS ranging from 22 for coconut to 57 for guava (Supplementary Fig. 1). For legumes, nuts, and



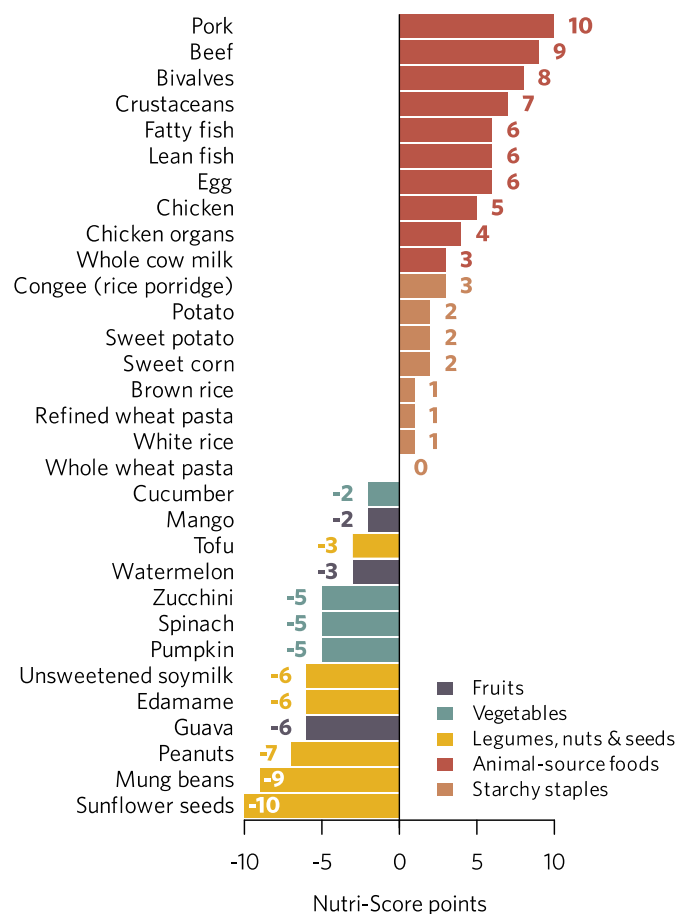
seeds, the range is narrower, from 44 for oncom to 68 for edamame (Supplementary Fig. 2). Animal source foods show wide variation, with the NVS ranging from 47 for cottage cheese to 91 for chicken organs (Supplementary Fig. 3). Finally, among starchy staples the NVS ranges from just 1 for congee up to 55 for sweet potato (Supplementary Fig. 4). In summary, there is variation within each food group, but the extent differs, with fruits, vegetables, animal source foods, and starchy staples showing wider NVS ranges compared to legumes, nuts, and seeds.



**Fig. 4 | Nutritional Value Scores for common Indonesian vegetables.** The Nutritional Value Score rates foods by nutritional value. It is scaled from 1 (lowest) to 100 (highest).

## Comparison with existing systems

We compared the NVS results for Indonesian foods with Nutri-Score and its underlying points and Health Star Rating and its underlying scores. For Nutri-Score points, the top scoring Indonesian foods ( $\leq 0$  points and a score of A) are most legumes, nuts, seeds, fruits, and vegetables, as well as some starchy staples like breadfruit, taro, and whole wheat pasta (Supplementary Table 4, Fig. 5). Moderately high scoring foods (1–2 points and a score of B) include some refined grains like white rice and refined wheat pasta, some whole grains like brown rice and whole wheat noodles, some white roots, tubers, and plantains, and some unprocessed lean red meats like buffalo and goat (Supplementary Table 4, Fig. 5). The bottom scoring foods ( $\geq 3$  points and a score of C or lower) include most animal source foods like dairy, all but the leanest red meat, poultry, fish and seafood, eggs, organ meat, as well as coconut, cassava, and congee (Supplementary Table 4, Fig. 5). Due to the contrasting scores for animal source foods, Nutri-Score points are not significantly linearly correlated with the NVS for animal source foods (Supplementary Fig. 11). For plant-source foods, however, there is a significant linear relationship ( $p < 0.001$ ), where poorer scoring foods according to Nutri-Score points correspond with lower scoring foods based on the NVS (Supplementary Fig. 11).



**Fig. 5 | Nutri-Score points for common Indonesian foods.** Nutri-Score points range from -15 (best) to 40 (worst).

In contrast to Nutri-Score, there is a significant relationship ( $p < 0.05$ ) between Health Star Rating scores and the NVS across all foods in Indonesia (Supplementary Fig. 12). In Health Star Rating, fresh fruits and vegetables other than coconut receive the top rating (5 stars), and many legumes, nuts, and seeds also receive the top scores and a rating of 5 stars (Supplementary Table 4, Supplementary Fig. 13). Many animal source foods also score highly, including unprocessed lean red meats, yogurt, chicken organs, and chicken (all 4.5 stars), as well as fish and seafood (4 stars; Supplementary Table 4, Supplementary Fig. 13).

## **Implications for life cycle analysis**

Environmental life cycle analyses typically assess the environmental impacts of foods in terms of kgs. However, such practices fail to account for variation in nutritional value across and within food groups. Within vegetables, for example, cucumber has a lower nutritional value than spinach (Fig. 3)—yet a typical environmental impact assessment would equate 1 kg of cucumber to 1 kg of spinach. Comparing foods in terms of Calories also inadequately accounts for nutritional differences. Within fruits, for example, watermelon has a lower nutritional value than mango (Fig. 3)—yet a typical environmental impact assessment would equate 1,000 Calories of watermelon to 1,000 Calories of mango.

The NVS offers a more nutritionally appropriate way to assess environmental impacts of foods by measuring the nutritional value produced and standardizing it for comparisons within and across food groups. To illustrate, just 234 g of spinach is needed for a NVS of 100 whereas 527 g of cucumber is needed to achieve the same NVS (Supplementary Fig. 14). It is also more appropriate to compare mango and watermelon using a fixed NVS rather than a fixed number of Calories. For example, just 659 Calories of mango is needed for a NVS of 100 whereas 1,004 Calories of watermelon is needed to achieve the same NVS (Supplementary Fig. 15).

## **Sensitivity analyses**

Each sensitivity analysis has different effects. Capping micronutrients at 50% of the Recommended Nutrient Intake favors foods containing a balance of micronutrients, while capping at 200% favors foods with very high quantities of one or two vitamins or minerals (Supplementary Tables 5–6). Shifting the weights of dietary attributes has a notable effect on the NVS. Plant-based foods tend to score much higher on the NCD-focused NVS while

nutrient-dense plant-source foods and animal source foods score higher on the nutrient-density-focused NVS (Supplementary Table 7). Winsorizing does not impact the relative ranking but moves foods near the highest and lowest NVS closer to the corresponding extreme (Supplementary Table 8). Not adjusting for bioavailability of iron and zinc has a small impact on the NVS per se, but significantly affects the mineral scores (Supplementary Table 9). Finally, using mass as the sole reference unit favors animal source foods and nuts and seeds; using energy as the sole reference unit favors nutrient-dense vegetables (Supplementary Table 10, Supplementary Figs. 16–17). More details of the sensitivity analyses are available in the Supplementary Material.

## Discussion

The NVS was able to identify recommended food sub-groups with high nutritional value, including organ meats, dark green leafy vegetables, and fish and seafood, from sub-groups with lower nutritional value, such as refined grains, demonstrating high discriminatory power across food sub-groups. In contrast, Nutri-Score assigned all organ meats and fish and seafood products a C rating yet assigned most refined grains a B rating. The NVS also provided more discriminatory power within broad food groups. For example, all fruits and vegetables except for coconut and cauliflower received A ratings according to Nutri-Score and 5 stars according to Health Star Rating; yet, the NVS rated fruits and vegetables with higher nutritional value like guava and spinach much higher than fruits and vegetables with lower nutritional value, like watermelon and eggplant. Health Star Ratings overall were more correlated with the NVS, scoring organ meats, lean meats, and fish and seafood 4 stars or higher.

The NVS and its component scores are useful for guiding policies and programs and can be tailored for target populations like women and young children. It complements food-based dietary guidelines because it discriminates the nutritional value of foods within commonly recommended food groups: fruits; vegetables; legumes, nuts, and seeds; animal source foods; and starchy staples<sup>9</sup>. Therefore, policy makers and program implementers can prioritize promoting and increasing access to the most nutritious foods within each broad food group to achieve greater health impacts.

The NVS is also designed for use as a functional unit in life cycle assessments to estimate environmental impacts per unit nutritional value. Identifying better options for such assessments is essential, as current practices vary widely<sup>10</sup>, with no scientific consensus<sup>12</sup>, and results tend to be unit-dependent<sup>13</sup>. For example, a landmark global environmental impact meta-analysis used functional units of mass, energy, and total protein content<sup>14</sup>. A more recent study<sup>15</sup> used this data along with updated environmental data on aquatic foods<sup>16</sup> and nutritional quality as assessed by the nutrient profiling system, Nutri-Score. Other researchers have used nutritional functional units based on nutrient density, for example as assessed by variations of the Nutrient Rich Foods index<sup>17</sup> or by priority micronutrient value<sup>18</sup>. The NVS, complemented by local food, nutrition, and environmental impact data, where available, can be used to compare the environmental impact of foods across or within food groups. Assessing environmental impacts per fixed NVS using local foods and food composition data places foods on nutritionally equivalent footing, improving upon prior metrics by incorporating contextually appropriate foods as well as aspects of priority nutrient density and protection against noncommunicable diseases. Food-based dietary guidelines could include the resulting insights to encourage consumption of context-appropriate sustainable healthy diets.

280

281 The NVS is also designed for use in food affordability assessments. Affordability of single  
282 foods has been assessed per unit energy<sup>19</sup>, priority micronutrient value<sup>20</sup>, and by the Nutrient  
283 Rich Foods index<sup>11</sup>. As with life cycle assessments, the NVS provides a more holistic way to  
284 standardize foods by nutritional value for food affordability assessments. Application of the  
285 NVS in food affordability assessments would provide insights to aid social protection  
286 programs in identifying the most affordable food sources of nutrition. Demand creation  
287 programs could focus on increasing consumer demand for the most affordable nutritious  
288 foods; at the same time, policies could help reduce the price of unaffordable nutritious foods,  
289 for example, by providing agricultural incentives, limiting the role of intermediaries in supply  
290 chains, improving infrastructure, and taking measures to counterbalance inflation<sup>21</sup>.

291

292 To determine initial validity and robustness of the NVS, we assessed content validity, face  
293 validity, and convergent validity, and conducted various sensitivity analyses. We tested  
294 content validity of the NVS algorithm through inclusion of dietary attributes of global health  
295 priority, comprising essential nutrients of public health concern<sup>22–26</sup> and dietary factors that  
296 indicate protection against noncommunicable diseases<sup>3,27,28</sup>. We tested face validity by  
297 implementing the NVS algorithm across recommended local foods available in Indonesia and  
298 Bangladesh, two disparate countries with a high burden of malnutrition. We tested convergent  
299 validity by comparing the NVS with Nutri-Score and Health Star Rating, two prominent  
300 nutrient profiling systems developed in high-income countries. Finally, we conducted  
301 sensitivity analyses of different component weights, micronutrient capping, winsorizing,  
302 bioavailability adjustments, and reference units to test the robustness of the NVS to various  
303 assumptions and parameters.

304

We were not able to assess discriminant validity since the NVS was developed to discriminate between foods recommended in global dietary guidelines. If the NVS was adapted and implemented across a broader range of foods, including ultraprocessed foods, then discriminant validity could be assessed. However, we caution against overreliance on validation of nutrient profiling systems against existing diet quality metrics, like the Healthy Eating Index, in which high scores can be achieved with over 90% of Calories from ultraprocessed foods<sup>29</sup>. This is because rigorous evidence from a randomized controlled trial found that a diet consisting of 80% of Calories from ultraprocessed foods led to substantial overeating and weight gain compared to a diet containing mostly unprocessed foods, even though meals within both diets were matched for presented Calories, macronutrients, sugar, sodium, and fiber<sup>30</sup>. Moreover, Healthy Eating Index scores have increased<sup>31</sup> alongside the obesity epidemic in the US, further calling into question the suitability of the Healthy Eating Index for validation of nutrient profiling systems through observational study designs<sup>32</sup>.

Future research could test the NVS for criterion validity<sup>33</sup> in diverse contexts, including correlating the NVS with essential nutrient biomarkers, anemia, stunting, noncommunicable disease markers, and mortality. Validation using observational studies, however, is limited due to confounding and various forms of bias, which can be difficult or impossible to properly adjust for<sup>34</sup>. Therefore, we recommend validating the NVS using a combination of criterion validation and randomized controlled trials which, when designed appropriately, account for both known and unknown confounders.

The NVS has many strengths. It follows recommendations for developing nutrient profiling systems for global use<sup>2</sup> by solely using essential nutrients of global health priority (excluding nutrients of little public health significance), analyzing locally available, commonly



consumed foods rather than foods popular in high-income countries, and offering flexibility for adaptation to country-specific contexts or populations. The NVS also uses nutrient ratios, which recent evidence suggests may identify noncommunicable disease risk more accurately than simply using limiting nutrients<sup>3</sup>. Moreover, the NVS follows best practices for developing nutrient profiling systems for use in environmental impact assessments<sup>10</sup>. Further, the NVS assesses the quantity *and* quality of essential micronutrients and macronutrients, including adjustments for nutrient bioavailability. Importantly, the NVS quantifies nutrient density in terms of mass *and* energy, which ensures foods are not unfairly penalized or benefited for having low or high Calorie density. Finally, the NVS offers nutritional component scores to provide more granular insights for researchers, policy makers, and program managers. These strengths make the NVS more suitable than existing systems for discriminating between foods and food groups recommended in dietary guidelines in low- and middle-income countries.

The NVS also has important limitations. It was developed for foods recommended in global dietary guidelines. If the NVS is to be used across a broader range of foods, including those not recommended in dietary guidelines, it may need to be adapted. This is particularly important, as diets worldwide are rapidly increasing in unhealthy ultraprocessed foods. Additionally, while many bioactive compounds have health benefits, we did not include them as a dietary attribute because food composition data only exists for certain phytochemicals highest in plant source foods and not bioactive compounds unique to animal source foods. We chose to exclude phytochemicals to avoid biasing the bioactive compound attribute against animal source foods. We also were unable to include dietary attributes related to fermented foods, since food composition data indicating beneficial microorganisms is lacking. Furthermore, given that national food composition tables for Indonesia and

Bangladesh include a limited set of foods and nutrients, which was insufficient to apply the NVS algorithm, we relied on USDA databases for most foods and dietary attributes. This necessary choice may have led to neglecting important differences in varieties, production methods, soil conditions, and culinary traditions that exist between the US and Indonesia and Bangladesh. Finally, we assessed the NVS for content validity, face validity, and convergent validity, but it has not yet been assessed for discriminant or criterion validity. Future studies could adapt the NVS for broader applications and further assess its validity.

The NVS provides a holistic metric to assess and compare the overall nutritional value of foods and specific nutritional components of interest, like micronutrients and essential amino acids. It captures multiple dietary components critical for global health and has many unique features that make it suitable for global applications. The NVS can be used to help policy makers and program implementers identify nutritious foods to prioritize for the greatest health impacts. Additionally, using the NVS as a functional unit could allow for more nutritionally equivalent comparisons in environmental impact and affordability assessments of foods. Further adaptations for a broader set of foods and validation studies are warranted, but the NVS shows promise for a range of applications to advance healthy and sustainable food systems.

## **Methods**

### **Nutritional Value Score**

The NVS aims to capture the variation in nutritional value across unprocessed, minimally processed, and processed foods recommended in global dietary guidelines, including fruits; vegetables; legumes, nuts, and seeds; animal source foods; and starchy staple foods. The NVS assesses the quantity and quality of essential nutrients as well as other dietary attributes

that protect against noncommunicable diseases. It is scaled (normalized) from 1 to 100, where 1 is the food with the lowest nutritional value and 100 is the food with the highest. We scaled the NVS across 170 total foods (127 unique foods) in Indonesia and Bangladesh, but future studies could scale the NVS across a broader set of foods in different countries. The NVS is the weighted average of seven normalized dietary attribute scores: vitamins (20%), minerals (20%), essential amino acids (12.5%), *n*-3 fatty acids (10%), fiber (7.5%), Calories (7.5%), and nutrient ratios (22.5%). We selected these attributes based on their global health priority and data availability across diverse foods in existing food composition databases.

Global diets are commonly lacking in essential vitamins, minerals, amino acids, and *n*-3 fatty acids<sup>22–26,35</sup>. We established their relative weights in the NVS based on the global prevalence and severity of health consequences of inadequacy and deficiency, and on the number of nutrients included in the attribute. The vitamins and minerals attributes make up 40% of the NVS because deficiency in one or more of four micronutrients is prevalent in over half of preschool-aged children (iron, zinc, and vitamin A) and two thirds of women of reproductive age (iron, zinc, and folate), causing substantial public health burden<sup>23</sup>. Moreover, estimated dietary inadequacies of numerous single micronutrients also show high prevalence worldwide<sup>25,26</sup>. We weighted the essential amino acids attribute 7.5 percentage points lower than the vitamins and minerals attributes because deficiency in essential amino acids is less prevalent but still poses a public health challenge globally<sup>24</sup>. We weighted the *n*-3 fatty acids attribute 10 percentage points lower than vitamins and minerals attributes because, while two thirds of adults are estimated to have low intake of DHA and EPA and one fifth are estimated to have inadequate intake of ALA<sup>22</sup>, the *n*-3 attribute includes just one essential nutrient while the vitamins, minerals, and essential amino acids attributes each include multiple essential nutrients.

We weighted the fiber attribute 12.5 percentage points lower than the vitamins and minerals attributes. This is because, although inadequate fiber intake is common worldwide<sup>28</sup>, fiber is not an essential nutrient. Also, like the *n*-3 attribute, fiber is the only component within the attribute. Additionally, the NVS assesses unprocessed, minimally processed, and processed foods recommended in dietary guidelines and thus do not substantially contribute to risk of noncommunicable diseases that fiber protects against. We weighted the Calories attribute the same as the fiber attribute and the individual nutrient ratios included in the nutrient ratio score to be consistent. We weighted the nutrient ratios attribute 2.5 percentage points higher than the vitamins and minerals attributes, since nutrient ratios are important for assessing risk of noncommunicable diseases, which are widespread globally and increasing<sup>3,27</sup>.

Each dietary attribute is described in further detail below.

## **Vitamins**

The vitamin score (*V*) reflects the quantity and quality of 11 vitamins of public health priority: folate, choline, riboflavin, thiamin, niacin, and vitamins A, B6, B12, C, D, and E. Low supply, low intake, or deficiency of these vitamins is common worldwide<sup>23,25,26,35</sup>. *V* is the average of two sub scores—*VE* and *VM*—each normalized between 1 and 100. *VE* reflects the vitamin density per unit energy. *VM* reflects the vitamin density per unit mass. Scoring foods per unit energy *and* mass ensures foods low in energy or mass are not unduly favored in the overall score. *VE* is calculated as follows:

$$VE_i = \frac{1}{A} \sum_{a \in A} \min \{ve_{a,i}, 1\}$$

where  $ve$  is the proportion of recommended nutrient intakes (RNIs) for each of the 11 vitamins ( $A$ ) provided in 300 Calories of each food ( $i$ ). Each vitamin's contribution to  $VE$  per 300 Calories was capped at the RNI to prevent foods very high in one vitamin from inflating the score. Although the chosen reference amount is arbitrary (as for all nutrient profiling systems), 300 Calories corresponds to about 13% of average energy requirements for moderately active individuals<sup>36</sup>, which represents a relatively plausible amount of energy to obtain from a single food in one day (except for low-Calorie foods).

$VM$  is calculated the same as  $VE$  but per 231 g of each food. This quantity was calculated by dividing 300 Calories by 1.3 Calories/g (the mean energy density of a minimally processed plant-based, low-fat diet and an animal-based, ketogenic diet)<sup>37</sup>.

## Minerals

The mineral score ( $M$ ) reflects the quantity and quality of five protective minerals of public health priority: iron, zinc, calcium, potassium, and magnesium. Low supply, low intake, or deficiency of these minerals is common worldwide<sup>23,25,26,35</sup>.  $M$  is the average of two sub scores— $ME$  and  $MM$ —each normalized between 1 and 100.  $ME$  reflects the mineral density per unit energy.  $MM$  reflects the mineral density per unit mass.  $ME$  is calculated as follows:

$$ME_i = \frac{1}{A} \sum_{a \in A} \min \{me_{a,i}, 1\}$$

where  $me$  is the proportion of RNIs for each of the five minerals ( $A$ ) provided in 300 Calories of each food ( $i$ ). Each mineral's contribution to  $ME$  per 300 Calories was capped at the RNI to prevent foods very high in one mineral from inflating the score. Iron and zinc contents were adjusted for bioavailability following Beal and Ortenzi (2022)<sup>38</sup>.

455

456 *MM* is calculated the same as *ME* but per 231 g of each food. This quantity was calculated by  
457 dividing 300 Calories by 1.3 Calories/g (the mean energy density of a minimally processed  
458 plant-based, low-fat diet and an animal-based, ketogenic diet)<sup>37</sup>.

459

## 460 **Essential amino acids**

461 The Essential Amino Acids score (*EAA*) reflects the quantity and quality of essential amino  
462 acids. *EAA* is the average of two sub scores—*ea* and *DIAAS*—each normalized between 1  
463 and 100. *ea* is the average of the sum of the essential amino acids per 300 Calories (*eaE*)  
464 and the sum of essential amino acids per 231 g (*eaM*). *DIAAS* is the untruncated Digestible  
465 Indispensable Amino Acids Score (DIAAS).

466

## 467 **n-3 fatty acids**

468 The *n-3* score (*n3*) reflects the quantity and quality of *n-3* fatty acids. *n3* is the average of two  
469 sub scores—*n3E* and *n3M*—each normalized between 1 and 100. *n3E* reflects the *n-3* fatty  
470 acid density per unit energy. *n3M* reflects the *n-3* fatty acid density per unit mass. *n3E* is  
471 calculated as follows:

472

$$473 \quad n3E_i = \max(DHA_i + EPA_i + DPA_i, ALA_i)$$

474

475 where *DHA+EPA+DPA* and *ALA* indicate the proportion of RNIs of long chain (250 mg) and  
476 short chain (1,240 mg) *n-3* fatty acids, respectively, provided in 300 Calories of each food (*i*).  
477 *n3M* is calculated the same as *n3E* but per 231 g of each food.

478

## **Fiber**

The fiber score ( $F$ ) reflects the quantity of fiber.  $F$  is average of two sub scores— $FE$  and  $FM$ —each normalized between 1 and 100.  $FE$  is the quantity of fiber in 300 Calories of each food.  $FM$  is the quantity of fiber in 231 g of each food.

## **Calories**

The Calories score ( $C$ ) reflects the quantity of Calories.  $C$  is the energy:mass ratio, normalized between  $-100$  and  $0$ . We assigned zero values to foods containing  $<1.3$  Calories/g (the mean energy density of a minimally processed plant-based, low-fat diet and an animal-based, ketogenic diet)<sup>37</sup>, to avoid penalizing foods with moderate Calorie density.

## **Nutrient ratios**

The nutrient ratios score ( $NR$ ) reflects the increased risk for noncommunicable diseases from consuming foods high in carbohydrates and low in fiber, high in sodium and low in potassium, and high in saturated fat and low in unsaturated fat<sup>3,27</sup>.  $NR$  is the average of three negative sub scores each normalized between  $-100$  and  $0$ :  $CFR$ ,  $NaKR$ , and  $SUR$ .  $NR$  is normalized between 1 and 100.  $CFR$  is the carbohydrate:fiber ratio. We assigned zero  $CFR$  values to animal source foods containing no added sugar or starch, since naturally occurring carbohydrates in animal source foods are not associated with health risk<sup>39</sup>. We also did this for unsweetened soymilk to be consistent with our treatment of cow milk.  $NaKR$  is the sodium:potassium ratio. We assigned zero  $NaKR$  values to foods containing  $<0.9$  mg sodium/Calorie, in alignment with the World Health Organization's recommendations for adults to limit daily sodium intake to  $<2,000$  mg (assuming an average energy requirement of 2,227 kcal for moderately active individuals<sup>36</sup>).  $SUR$  is the SFA:UFA ratio. We assigned zero

*SUR* values to foods containing <10% of energy from fat, to avoid penalizing foods containing small quantities of fat overall for having minimal quantities of saturated fats.

### **Liquid dairy and dairy alternatives**

For unsweetened milk, kefir, and semi-liquid yogurts, including plant-based varieties, we based the scores for *V*, *M*, *ea*, *n3*, and *F* exclusively on *VE*, *ME*, *eaE*, *n3E*, and *FE*, respectively, since they are low in Calories, and their mass is not a barrier to consumption as it is with solid foods. We scaled powdered milk to the same energy density as liquid milk, so that it would be analyzed in the form typically consumed.

### **Nutrient Density Score**

The Nutrient Density Score reflects the overall quantity and quality of essential nutrients of public health priority. The Nutrient Density Score is normalized between 1 and 100 where 1 represents the food with the lowest nutrient density and 100 represents the food with the highest nutrient density. The Nutrient Density Score is the weighted average of four normalized dietary attribute scores: vitamins (35%), minerals (35%), essential amino acids (20%), *n*-3 fatty acids (10%).

### **Software**

All analyses were conducted using R version 4.3.1.

### **Food composition data**

For the NVS analysis, we built a master food composition database for Indonesian and Bangladeshi foods, with values for Calories, carbohydrates, fiber, mono and polyunsaturated fatty acids, saturated fatty acids, 11 vitamins, 6 minerals, short and long chain *n*-3 fatty acids,



essential amino acids, DIAAS, and phytate<sup>40</sup>. We also developed a modified version of the master database, including only Indonesian foods and six additional components required to apply the Nutri-Score and Health Star Rating algorithms (more details available in the Supplementary Material).

Values for most foods and for all nutrients were obtained from USDA databases<sup>41</sup>, complemented by the Indonesian and Bangladeshi food composition tables for specific local foods which were not available in USDA databases<sup>42</sup>. The choice to primarily rely on USDA data was due to the limited set of foods and nutrients included in national food composition tables, which was insufficient to implement the NVS algorithm. In fact, even for the specific local foods which we extracted from the Indonesian and Bangladeshi food composition tables, we had to use food sub-group average values from USDA databases to fill in the gaps for any nutrients not included in the national food composition tables. Values for DIAAS were obtained from the literature, by prioritizing studies conducted in humans, followed by those conducted in pigs and, as a third option, rats, and by preferring average over single values when available.

Our analysis was limited to unprocessed, minimally processed, and processed foods recommended in dietary guidelines globally<sup>9</sup>. These are the sentinel foods listed in the country-adapted Diet Quality Questionnaires for Indonesia and Bangladesh ([dietquality.org](http://dietquality.org)), which ensure our analysis focused on locally available, commonly consumed foods. We compiled data on the composition of foods as they are usually consumed, whether raw, cooked, or both. Where applicable and where data were available, nutrient values for multiple cooking methods for the same food were averaged. In addition, for meat, nutrient densities for various cuts and portions of the same animal were averaged. With regards to aggregate

sentinel foods (for example, fish, cheese, rice), food composition data from different species or varieties were collected and averaged (for example, fish species popular in Indonesia or Bangladesh, various types of hard and soft cheese, different varieties of rice). Furthermore, although not reflected in the country-adapted Diet Quality Questionnaires for Indonesia and Bangladesh, we separated fatty from lean fish, full-fat from low-fat cheese, and whole grains from refined grains, because of the significant differences in food composition and nutritional value between these food sub-groups.

Missing values for individual foods were replaced by the corresponding average values for all foods within a given Diet Quality Questionnaire question. For instance, if the vitamin E density of water spinach (question 6.1 in the Diet Quality Questionnaire for Indonesia) was missing, the average value for all vegetables under question 6.1 would be used, assuming that foods belonging to the same Diet Quality Questionnaire question have comparable nutrient density. This approach allowed us to fill all data gaps except for ALA, whose value was only available for a limited set of foods in USDA databases, and for which we sometimes had to rely on available literature.

For more details on the food composition data, please refer to the Supplementary Material and the Extended Data file.

### **Dietary reference intakes**

For vitamins and minerals, we used harmonized nutrient reference values, which recommend a mix of values from the European Food Safety Authority and the Institute of Medicine, depending on the micronutrient (Supplementary Tables 1–2)<sup>43</sup>. For *n*-3's we used European Food Safety Authority RNIs.

578

## 579 **Sensitivity analyses**

580 We conducted five sensitivity analyses. First, we capped vitamin and mineral contents at 50%  
581 and 200% of the RNI. Second, we shifted the weights of dietary attributes towards protection  
582 against noncommunicable disease: *V* (10%), *M* (10%), *EAA* (10%), *n3* (12.5%), *F* (15%), *C*  
583 (15%), and *NR* (27.5%); and nutrient density: *V* (30%), *M* (30%), *EAA* (20%), *n3* (10%), *F*  
584 (2.5%), *C* (2.5%), *NR* (5%). Third, we winsorized the NVS by truncating outliers at the 5<sup>th</sup>  
585 and 95<sup>th</sup> percentiles. Fourth, we applied the NVS algorithm without adjusting for  
586 bioavailability of iron and zinc, by assuming 15% iron bioavailability and 35% zinc  
587 bioavailability for all foods indistinctly. Last, we calculated the NVS when using mass or  
588 energy as the sole reference unit.

589

## 590 **Data Availability**

591 All data are publicly available in cited references and in the Extended Data.

592

## 593 **Code Availability**

594 All code will be made available on GitHub before the time of publication.

595

## 596 **Acknowledgements**

597 We thank Saul Morris, Stella Nordhagen, Allison O’Leary, and Bree Beal for their feedback  
598 on a draft version of this article. This work was supported by the Dutch Ministry of Foreign  
599 Affairs.

600

## 601 **Author contributions**

602 T.B and F.O developed the theory and methods and co-wrote the manuscript.

## Competing interest declaration

The authors declare no competing interests.

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## Tables

**Table 1 | Nutritional scores for common Indonesian foods**

Food	Vitamin score	Mineral score	n-3 fatty acid score	EAA score	Fiber score	Nutrient ratio score	Calorie score	Nutrient Density Score	Nutritional Value Score
Spinach	75	90	15	48	68	99	0	92	99
Chicken organs	92	63	1	82	1	99	-10	95	91
Pumpkin leaves	64	67	9	53	90	100	0	75	90
Water spinach	65	68	14	44	67	99	0	75	87
Chinese cabbage	60	66	21	42	49	99	0	72	84
Beef organs	80	53	2	84	1	98	-12	85	84
Fatty fish	61	26	100	75	2	99	-15	73	83
Chinese broccoli	60	56	12	42	73	99	0	66	82
Moringa leaves	72	60	4	50	29	97	0	75	81
Deer	61	58	1	92	1	96	-6	80	81
Sweet potato leaves	53	51	5	49	70	99	0	61	78
Bivalves	39	56	52	68	2	97	-7	68	76
Goat	41	55	1	89	1	99	-3	68	74
Buffalo	51	40	1	94	1	99	0	67	74
Broccoli	58	41	8	38	63	99	0	55	73
Cassava leaves	49	59	4	42	33	98	0	61	73
Horse	40	50	4	94	1	99	-10	66	72
Crustaceans	41	37	37	78	2	95	0	61	71
Bitter melon	38	48	8	34	69	99	0	47	69
Zucchini	47	49	9	35	41	97	0	53	69
Boar	40	33	4	100	1	99	-6	60	69

Food	Vitamin score	Mineral score	n-3 fatty acid score	EAA score	Fiber score	Nutrient ratio score	Calorie score	Nutrient Density Score	Nutritional Value Score
Cabbage	44	42	9	35	61	99	0	48	69
Dove	40	48	8	74	1	99	-18	60	68
Edamame	33	41	10	55	51	99	0	48	68
Rabbit	42	33	3	95	1	99	-13	60	68
Red beans	32	33	12	41	81	99	0	40	66
Sunflower seeds	52	59	2	41	62	99	-98	61	65
Beef	35	43	2	77	1	98	-29	55	62
Green pepper	33	34	1	34	69	99	0	37	62
Radish	29	41	1	34	62	99	0	39	62
Mung beans	24	27	11	45	80	99	0	34	62
Lamb	37	38	1	77	1	98	-26	54	62
Green beans	35	27	6	35	68	99	0	36	61
Tree fern	46	6	5	50	71	98	0	35	61
Tomatoes	40	35	9	33	33	98	0	42	61
Pumpkin	45	39	1	32	24	96	0	45	60
Lean fish	36	16	22	79	2	99	-8	46	60
Mung bean sprouts	38	37	1	40	29	97	0	43	60
Pork	43	25	3	83	1	99	-34	52	60
Carrots	39	25	1	35	58	98	0	36	60
Egg	49	18	9	63	1	97	-7	47	59
Long bean	31	38	5	38	33	97	0	40	59
Tempeh	19	38	8	60	32	98	-14	41	59
Chicken	30	24	8	78	1	99	-17	44	57
Guava	33	22	3	27	73	97	0	30	57
Tofu	11	39	10	54	16	99	-1	36	55
Sweet potato	33	19	1	52	31	96	0	35	55
Mushrooms	35	24	1	34	30	97	0	33	54
Unsweetened soymilk	19	19	27	55	9	100	0	33	54
Rose apple	29	16	11	28	58	99	0	26	54
Winged beans	14	46	3	44	18	95	-4	37	54
Peanuts	39	47	1	30	54	99	-98	46	54
Plain whole yogurt	23	27	7	61	1	94	0	37	53
Red pepper	47	12	1	30	25	98	0	32	53
Whole cow milk	28	22	6	59	1	95	0	37	53

Food	Vitamin score	Mineral score	n-3 fatty acid score	EAA score	Fiber score	Nutrient ratio score	Calorie score	Nutrient Density Score	Nutritional Value Score
Whole milk powder	25	23	6	59	1	95	0	36	52
Whole sheep milk	26	21	5	64	1	94	0	36	52
Cantaloupe	37	22	9	26	20	94	0	32	51
Avocado	25	18	3	26	58	99	-6	24	51
Starfruit	21	13	9	28	65	99	0	20	51
Luffa gourd	20	25	5	31	40	97	0	26	51
Full-fat cheese	25	42	3	78	1	80	-50	50	50
Duck	27	22	1	63	1	99	-35	37	50
Orange	29	15	7	26	42	97	0	24	50
Papaya	30	18	7	24	32	96	0	26	49
Potato	19	20	2	53	20	93	0	29	49
Green pepper	31	11	4	30	25	98	0	24	48
Durian	29	16	6	24	35	96	-4	24	48
Peanut butter	34	42	1	28	40	98	-100	40	47
Low-fat cottage cheese	13	6	4	94	1	90	-3	31	47
Taro	20	19	2	25	47	96	-3	21	47
Cashews	18	64	2	26	20	93	-95	43	46
Grapefruit	27	12	9	25	26	95	0	22	46
Breadfruit	17	17	2	26	46	95	0	19	46
Mango	32	9	6	26	24	94	0	23	46
Tangerine	24	13	6	25	29	95	0	21	45
Cauliflower	31	11	1	31	20	94	0	24	45
Whole wheat pasta	15	22	2	25	35	95	-4	20	45
Oncom	6	46	8	48	7	78	-15	35	44
Pineapple	26	11	7	25	24	94	0	20	44
Cucumber	14	23	6	32	14	94	0	22	44
Banana	19	16	3	26	30	94	0	19	44
Whole wheat noodles	15	22	1	23	36	91	-4	20	43
Longans	28	11	3	26	17	91	0	21	42
Sweet corn	18	15	2	17	29	94	0	16	41
Pear	7	7	10	24	47	97	0	9	41

Food	Vitamin score	Mineral score	n-3 fatty acid score	EAA score	Fiber score	Nutrient ratio score	Calorie score	Nutrient Density Score	Nutritional Value Score
Eggplant	18	9	3	29	22	93	0	16	41
Dragon fruit	7	7	3	26	47	97	0	9	40
Green banana	17	18	3	26	16	87	-1	20	40
Unsalted brown rice cakes	18	34	1	25	28	87	-55	28	39
Apple	7	5	11	24	39	97	0	9	39
Snake fruit	26	30	8	24	6	64	0	30	37
Brown rice	13	14	1	21	18	90	0	13	37
Refined wheat pasta	3	6	1	24	16	89	-6	6	30
Watermelon	6	4	2	24	5	87	0	7	30
Cassava	14	10	2	1	16	85	-13	7	29
White rice noodles	1	1	2	21	11	84	0	1	26
Coconut	6	19	3	27	61	50	-48	15	22
White rice	3	4	2	21	5	51	0	4	15
Congee (rice porridge)	11	6	2	30	3	1	0	11	1