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Data-driven development and validation of a nutrient-based score to measure nutritional balance of meals in the Philippines

Fabio Mainardi[1*], Richard G. Côté[1], Nele Kristin Silber[1], Roko Plestina[1], Eldridge Ferrer[2] and Imelda Angeles-Agdeppa[2]

Abstract

Background The goal of the present study was to design an easily computable score, based on nutrient composition data instead of food groups, to evaluate the nutritional quality and balance of meals, adapted to the nutritional recommendations for Filipino adults.

Method The score was defined as a weighted average of 9 nutrient scores. Protein, total fat, saturated fat, free sugars were scored as % of energy; calcium, fiber, sodium, vitamin C, magnesium were scored based on the local dietary reference intakes. The scoring algorithm was an adaption of a score previously developed by the authors based on US data. In the present study, the score was applied to 69,923 meals reported by 31,218 adult Filipinos aged 20 to 59 in the 2018 edition of the Philippine Expanded National Nutrition Survey to evaluate its validity and compare against exemplary meals designed as part of 24 h diet plans that meet local dietary guidelines.

Results Meals from these exemplary menu plans, developed by local nutrition experts, scored on average 72.2 ± 13.9 (mean ± standard deviation) while those of survey participants scored 46.1 ± 12.9. Meal scores were significantly associated with the density of positive micronutrients (e.g., Vit A, Vit C) and favourable food groups (e.g. fruits, whole grains) not directly included in the algorithm.

Conclusion The score, between 0 and 100, is a valid tool to assess the nutritional quality of meals consumed by the PH population, accounting for both shortfall and excess nutrients, adjusted for the energy content of the meal. If applied to consumer-facing applications, it could potentially help users to understand which meals are nutritionally balanced.

Keywords Nutritional scoring, Meal balance, Nutritional survey analysis, Balanced diet, Nutritional recommendations, Nutritional quality in the Philippines

*Correspondence:
Fabio Mainardi
fabio.mainardi@rd.nestle.com
[1]Nestlé Institute of Health Sciences, Nestlé Research, Société des Produits Nestlé SA, Lausanne, Switzerland
[2]Food and Nutrition Research Institute, Department of Science and Technology, Gen. Santos Avenue, Bicutan, Taguig City 1631, Philippines

Background

The purpose of this research was to develop and test an index of meal quality for the adult Filipino population. The Filipino version of the Healthy Eating Index was revised recently [1] and provides a measure of adherence to the local food-based dietary guidelines. However, the understanding of meal patterns and meal quality may provide the basis for actionable dietary recommendations in everyday life [2, 3]. For example, an increasingly popular way to seek recipe inspiration and menu planning is through online culinary recipe websites. Artificial Intelligence (AI) may be used to rank and prioritize the presented content through retrieval algorithms, typically based on some measures of popularity, independently of the nutritional content [4, 5]. Usually, little nutritional guidance is given to the user on how to build a balanced meal around the selected recipe, for example through the choice of a side-dish or an appetizer. Moreover, studies show that the nutritional quality of online recipes often have a low nutritional density [6]. Scores to evaluate nutritional quality are often based on unfavourable nutrients (fats, sugar, sodium) and there is a need to develop metrics which can better estimate the ratio of favourable nutrients and energy. Such an algorithm to evaluate the nutritional quality of meals would therefore be a relevant tool to (a) rank recipes according to their nutritional value (b) use this ranking in combination with popularity in an online recommendation system, and (c) guide the user towards building more balanced meals by choosing optimal combinations of recipes for main and side-dishes.

Although public health authorities see the importance of nutrition for public health concerns, concrete activities to improve nutrition are mostly focused to food labelling [7, 8]. While there are a number of publications proposing metrics to measure overall diet quality and the quality of individual foods, relatively few publications have tried to assess specifically the quality of meals [7–9]. Furthermore, several existing indices for assessing meal quality target Western populations [10, 11]. We chose the Philippines as a case-study for non-Western dietary patterns because of the availability of recent, nationally representative, high-quality dietary intake data. In addition, nutrient inadequacy for several micronutrients is very high in the adult population in the Philippines [1, 12–14]. Our hypothesis was that the nutrient density of individual meals should reflect the nutrient adequacy assessed at a daily level [2, 3]. Indices looking at meal quality rather than diet could contribute to better food choices, by ranking recipes and meals in commercial settings (canteens, restaurants, etc.) or on recipe websites. Our focus on meals, composed of several items, provides actionable consumer guidance and a good compromise, when compared to the high burden of complete dietary intake capture and the limitations to on-pack nutrition guidance of individual products.

Our objectives were:

a) build on our previous research [15] and further investigate the relationship between diet quality and food choices,
b) test to what extent a nutritional quality score for meals could be predictive of the daily nutritional intake, in a non-Western dietary context,
c) confirm that our method could be applicable in a broader geographic context.

Previously, we developed a meal nutritional score that was applied to the US population and demonstrated that it could predict dietary quality [15]. In the present work, we investigated how to adapt the existing score to a country with a different culinary culture. The adaptation was made in three steps: (1) we replaced the US Daily Values with the local recommendations [16] (2) we reviewed the shortfall nutrients in the Filipino adult population [13] and (3) we applied a data-driven approach to select the smallest number of nutrients (details in the Methods). After adapting the score to the Filipino dietary guidelines [17], we assessed its association with diet quality. We hypothesized that nutritionally adequate diets should, on average, be composed of meals with higher scores. Since the average compliance with the dietary guidelines is known to be low in the Filipino population [13, 14], we hypothesized that this gap should be observed already at the level of the individual meals; in other words, the meals reported in the national dietary survey were expected to have low scores on average, compared to balanced meals composed of a variety of food groups.

To make our scoring algorithm easier to implement on culinary websites and other consumer-facing applications, we aimed at keeping the required nutritional input parameters as limited as possible and focusing on nutrients that were readily available in food composition tables, with a high level of data coverage, thereby reducing the burden of retrieving detailed nutritional information about the recipes.

Methods

Data: dietary intake and menu plans

For this study, data on dietary intakes was derived from the 2018 Expanded National Nutrition Survey (ENNS) dietary component survey [1, 18]. The ENNS is the official nationwide survey on nutritional status, diet, and other lifestyle-related risk factors for noncommunicable diseases. A 2-day, non-consecutive, 24-h food recall interview is conducted to estimate food intake. We used the first day of recall in the analysis, since our aim was to test the association between the quality of meals and the quality of daily intakes, rather than the estimation of habitual intakes. In addition, it is not clear how a statistical model like the National Cancer Institute (NCI) method [19] could be applied to meals. For more details about the ENNS study design, we refer to Angeles-Agdeppa et al. [1].

For the purpose of this study, we asked a dietitian to develop three 2-week menu plans, designed to adhere to the Filipino food-based dietary guidelines [17]. These three meal plans were designed according to three dietary patterns: Halal, Standard/Omnivore, and Vegetarian [1]. These meal plans for Filipino adults were based on food choices reflecting the characteristics of a local diet. All foods in the menu plans were assigned a food code corresponding to an item in the local food composition table, from which the nutrient content was derived. Importantly, the development of the menu plans was completely independent of the development of the meal score and based solely on the food -based guidelines. More details on the menu plans can be found in Angeles-Agdeppa et al. [12].

Definition of the score

We followed the methodology explained in Mainardi et al. [15]. The score was defined as the weighted arithmetic mean of nine nutrient scores. As in Mainardi et al. [15] the nutrients and their weights were chosen in a data-driven way, from an initial list of 15 nutrients: calcium, carbohydrate, fiber, free sugar, magnesium, potassium, protein, saturated fat, sodium, total fat, vitamin A, vitamin C, vitamin D, vitamin E and zinc. To each nutrient we assigned a weight of 0, 1, or 2, and tested the resulting 65’536 possible scores. Each candidate score, corresponding to a possible weighting, was applied to the each of the meals from the ENNS. We discarded all the scores that were not symmetrically distributed (tested through a signed rank test, with a significance level of 5%). In addition, we correlated the meal scores with the densities of the following food groups: fruits, whole grains, vegetables, nuts and seeds, sugar-sweetened beverages. Spearman correlations had to be positive, except for the sugar-sweetened beverages. In addition, correlations had to be statistically significant for all the food groups ($p<0.05$). After discarding all the weightings based on the above criteria, we screened the remaining options and selected one based on the strength of the correlations with the food groups.

For each nutrient, an ‘optimal range’ was defined, and nutrient amounts within that range received a score of 100; amounts below or above the range received a diminishing score from 100 to 0.

The scoring system is summarized in Fig. 1.

Fats, carbohydrates, free sugars and sodium are scored based on their % contribution to the total energy of the meal, while the other nutrients (fiber, minerals and vitamins) are scored based on their amounts scaled to 2000 kcals.

Two types of scoring functions were applied to different classes of nutrients. For the nutrients to limit (saturated fats, sodium and free sugars), the WHO recommendations were used to define the ranges. Saturated fats and free sugars receive a score of 100 if they represent at most 10% of energy and sodium receives a score of 100 for levels below 2000 mg/2000 kcal [20, 21].

For micronutrients, a score of zero was given when intake was lower than 0.5 × Daily Value (DV). For micronutrient intakes above the healthy range, a score of zero was given when intake was higher than 200% DRI.

For protein, fiber, total fat, vitamin C, calcium, magnesium, the ranges were defined based on the local recommendations [22], as reported in Filipino administrative order on prepackaged food labelling from 2014[22,] as reported in Table 1.

Statistical analysis

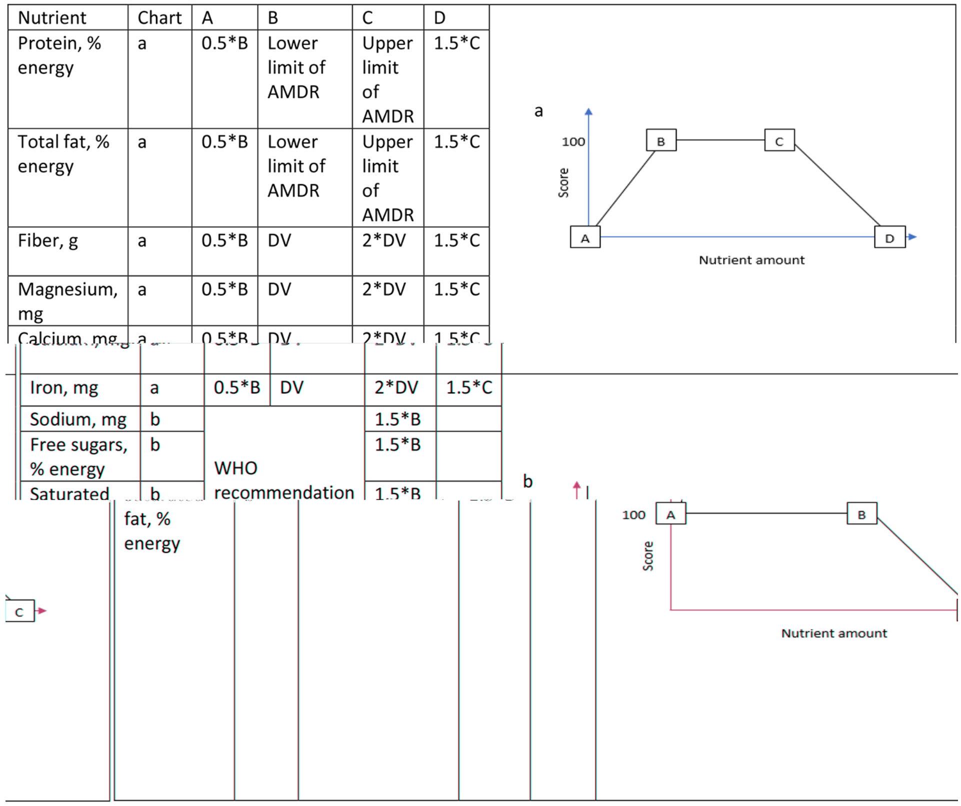
We excluded from the analyses reported daily intakes that were considered as outliers based on energy. We defined the outliers according to Tukey’s definition [23] with k = 4: outliers are defined as values outside the interval [Q1–4(Q3-Q1), Q3 + 4(Q3-Q1)], where Q1, Q3 are the first and third quartiles.

The score being a weighted sum of individual nutrient scores, we calculated the correlation matrix of the nutrient scores, and used principal component analysis (PCA) to explore how many nutrients are required to explain any given fraction of the total variance. These analyses help to understand the underlying structure of the score, and to determine whether 1 or more dimensions accounted for the variation in the data. PCA, based on the correlations among the individual components, determines the number of independent dimensions that compose the score.

All the meals in the three exemplary menu plans were scored and their scores were compared (Wilcoxon test) with the scores of the meals reported in the dietary components of the ENNS [1, 13].

We report, for each meal type, the food group content between the first and third tertiles of meal scores. We investigated the association with a few food groups that were readily available to us in the data: whole grains, vegetables, fruits and sugar-sweetened beverages. It is expected that, for ‘positive’ food groups like fruits and whole grains, the food group content should be higher in the third tertile of meal scores than in the first tertile. Inversely, for Sugars and Sweetened beverages, the third tertile should correspond to a lower content.

Since the score is based on relatively few selected nutrients, we compared the distribution of several key



Nutrient	Chart	A	B	C	D
Protein, % energy	a	0.5*B	Lower limit of AMDR	Upper limit of AMDR	1.5*C
Total fat, % energy	a	0.5*B	Lower limit of AMDR	Upper limit of AMDR	1.5*C
Fiber, g	a	0.5*B	DV	2*DV	1.5*C
Magnesium, mg	a	0.5*B	DV	2*DV	1.5*C
Calcium, mg	a	0.5*B	DV	2*DV	1.5*C
Iron, mg	a	0.5*B	DV	2*DV	1.5*C
Sodium, mg	b	WHO recommendation		1.5*B	
Free sugars, % energy	b			1.5*B	
Saturated fat, % energy	b			1.5*B	

Fig. 1 Description of the scoring system. The panels on the right show how nutrient amounts are scored. Nutrients to limit (free sugar, saturated fat, sodium) are scored according to the function of type **b**) where amounts below a lower limit are awarded 100 points and amounts above an upper limit are scored 0. Intermediate amounts are scored proportionally. The remaining nutrients are scored according to a function of type **a**), where amounts below an upper limit are also given a zero score

Table 1 Nutrient intake recommendations from the Filipino national foods and drugs administration, based on a 2000 kcals reference

Nutrient	Minimum intake	Maximum intake
Calcium	750 mg	
Fiber	20 g	
Magnesium	240 mg	
Protein	10% of energy	15% of energy
Total fat	15% of energy	30% of energy
Vitamin C	70 mg	

nutrients between tertiles of meal scores, including nutrients not used in the calculation of the score: calcium, carbohydrates, total fat, fiber, free sugars, iron, magnesium, potassium, protein, saturated fat, vitamin A, vitamin C, vitamin D, vitamin E. We applied a Kruskal-Wallis test followed by a Dunn post-hoc comparison test with Benjamini-Hochberg correction to the distribution of each of these nutrients within each tertile of scores, separately for each meal type.

Results

Nutrients that were selected for inclusion in the current score are the following 9 nutrients and weights: protein (w=1), total fat (w=1), fiber (w=2), magnesium (w=1), calcium (w=1), vitamin C (w=1), sodium (w=1), free sugars (w=1) and saturated fat (w=1).

Scores of meals from population data

The survey data represents a population of 19,623 subjects, spanning an age range 19–95, with a slightly higher proportion of females (55%).

In total, 69223 meals were reported, breakfast, lunch and supper being the most frequent meals (Table 2). Only 86 subjects reported consuming all meal occasions while 9126 reported only the three main meals (breakfast, lunch, supper).

Meals in the menu plans were scored based on their nutrient content, as calculated by mapping the foods to the local food composition table. Meals in the menu plans scored significantly higher than the corresponding meals in the ENNS data (Table 2, all p-values < 0.05). For example, the median score for lunch was 48, with an inter-quartile range of 44–56,

Table 2 Summary of scores and energy by meal type. Late night snacks were not provided in the menu plans, *N* = 14 (2 weeks) for each meal in the menu plans

	AM snack, *N* = 3461[1]	breakfast, *N* = 19,011[1]	late night snack, *N* = 727[1]	lunch, *N* = 18,899[1]	PM snack, *N* = 7971[1]	supper *N* = 19,154[1]
Dietary intake (ENNS)						
SCORE	41 (31, 49)	43 (33, 51)	36 (27, 45)	48 (44, 56)	38 (27, 48)	47 (43, 54)
KCAL	186 (118, 295)	357 (217, 531)	123 (72, 247)	424 (307, 606)	162 (102, 256)	406 (292, 585)
Developed Menu Plans	*N* = 14	*N* = 14		*N* = 14	*N* = 14	*N* = 14
SCORE (Standard)	75 (67, 78)	78 (75, 84)		81 (70, 84)	63 (58, 77)	73 (67, 79)
SCORE (Halal)	75 (55, 83)	70 (58, 78)		73 (68, 78)	65 (55, 79)	77 (68. 81)
SCORE (Vegetarian)	74 (63, 81)	77 (74, 86)		76 (63. 83)	70 (66, 75)	78 (72, 85)

[1]Median (IQR)

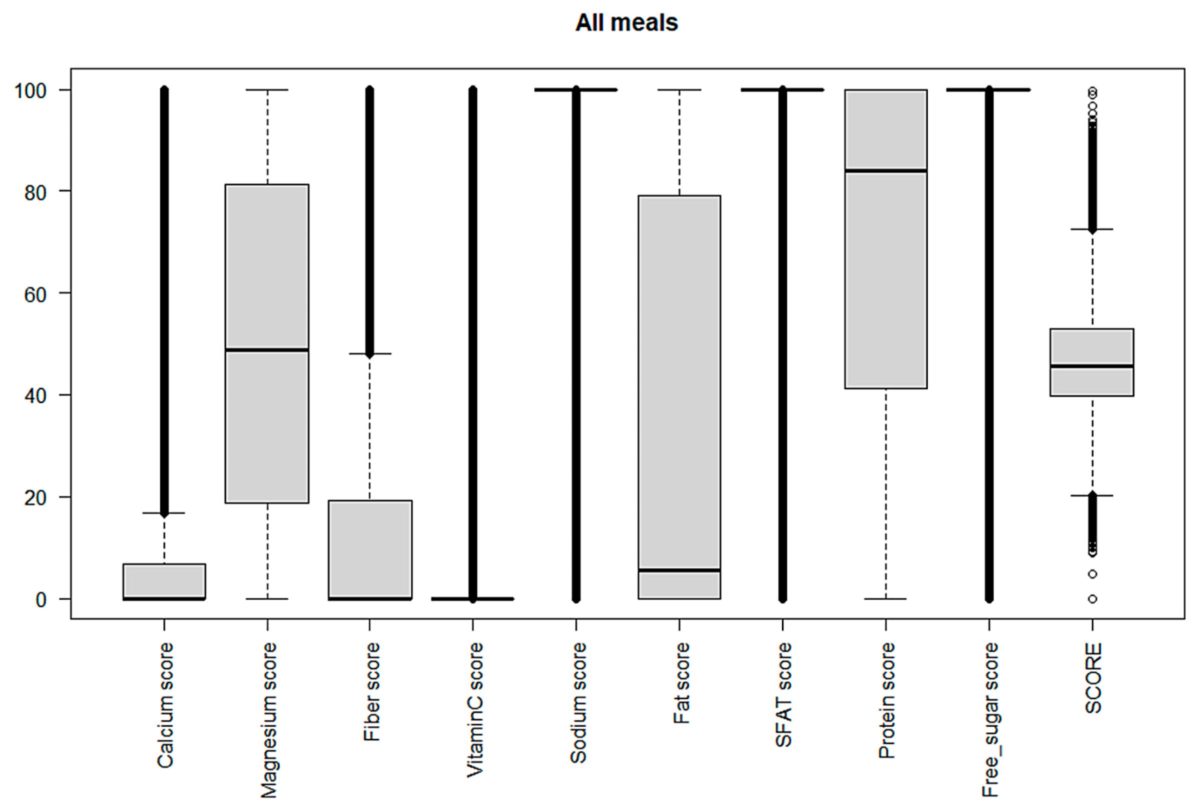


Fig. 2 Distribution of scores, total and per nutrient

while the median score was 81 (IQR = 70–84) in the standard menu plan. Afternoon snacks had the lowest scores, both in the ENNS data and in the menu plans. For the other eating occasions, all the median scores were at least 70 in the menu plans, and below 50 in the ENNS meals. In general, we observed that inter-quartile ranges did not overlap between the 2 datasets; for instance, 75% of breakfast scores were below 51 in the ENNS data, while only 25% of the breakfast scores were below 74 in the vegetarian menu plan.

On average, lunch and supper were the most calorie-rich meals in the ENNS data (Wilcoxon test, p < 0.05).

The mean scores for males and females were respectively, 46 (12) and 46 (13) (mean (SD)), all meals included. Scores were very weakly correlated with age: for each meal type, the Spearman correlation was highly significant but below 0.1. The scores for the individual nutrients varied greatly, the lowest scores were observed for vitamin C, fiber and calcium, while scores for free sugars, sodium and SFA were generally high (Fig. 2).

PCA showed that at least 8 principal components are needed to explain at least 90% of the variance (Fig. 3). The first principal component explained only about 19% of the total variance of the score.

The highest correlation between the total score and the nutrient scores was found for magnesium (0.6,Fig. 4).

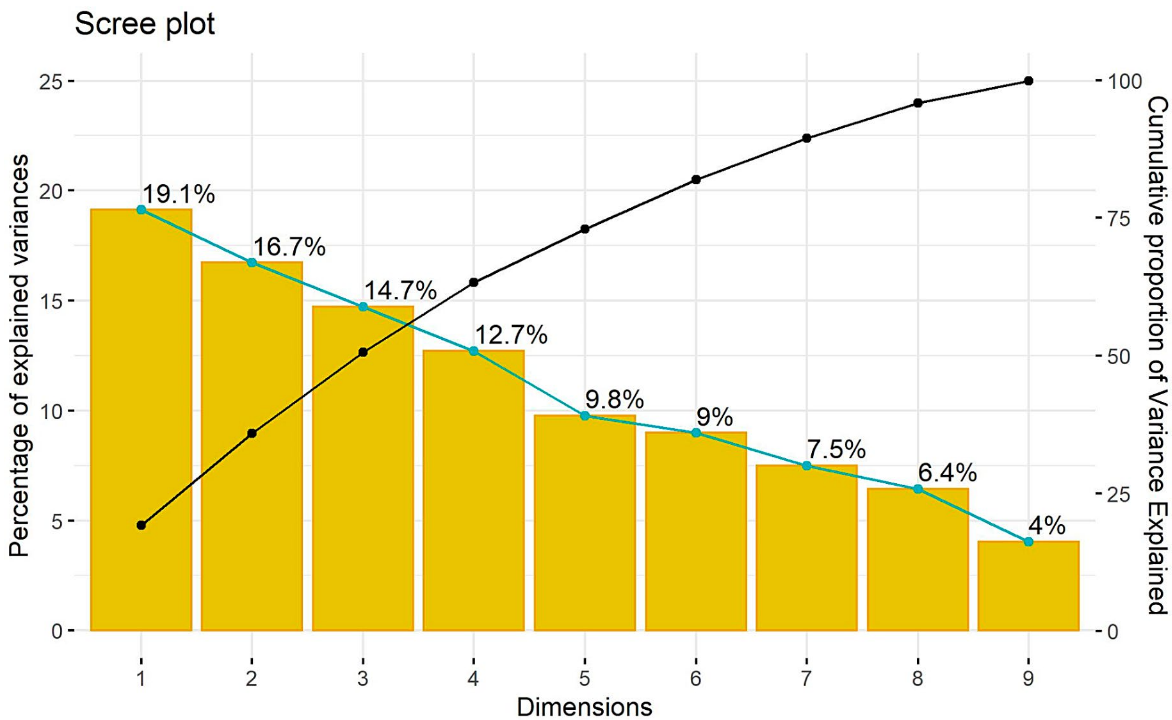


Fig. 3 A PCA was applied to the set of nutrient scores calculated on the ENNS data. Each dimension on the X axis represents a principal component (i.e., a linear combination of scores). Bars represent the % of variance explained by each component. The black line represents the cumulative fraction of variance explained. At least 6 dimensions are needed to explain 80% of the variance

Scores for saturated fatty acids (SFA) and total fat were negatively correlated (ρ=-0.35). All correlations were statistically significant.

The correlation between the caloric content of the meal and its score varied significantly depending on the meal occasion, with a maximum value of 0.39 for breakfast (Table 3).

Association with densities of nutrients and food groups

We compared the content of macro- and micro-nutrients, and of food groups, across tertiles of meal scores. We will refer to the tertiles as T1 (lowest third of scores), T2 (between lowest third and highest third of scores) and T3 (highest third of scores). In Tables 4, 5 and 6 we display the results for breakfast, lunch and supper. The tables also include nutrients that were not used in the calculation of the score: total carbohydrates, potassium, vitamin A, vitamin D, vitamin E. For each tertile of scores, we reported the average content and standard deviation of nutrients and food groups, with a pairwise comparison for statistical difference of each variable (nutrient or food group) between the tertiles.

Pairwise comparisons of food groups and nutrients across tertiles of scores were generally statistically significant, with a few exceptions (namely saturated fat and vitamin D, see Tables 5 and 6). Fiber, vitamin A, vitamin C and vitamin E amounts significantly increased across the tertiles of scores of breakfast, lunch and supper. For example, in breakfast, fiber increased from 5.3 g in tertile T1 to 7.2 g in T2 and 12.6 g in T3. A similar pattern for fiber was observed in lunch and supper, although the rate of increase was less steep. Free sugars decreased across tertiles of scores in breakfast, lunch and supper, with a sharper drop from tertile T1 to T2; the difference between T2 and T3 was smaller, and not significant for lunch (Table 5).

For other nutrients, the comparisons gave slightly different results depending on the meal type. Fat and protein were positively associated with the tertiles of scores of breakfasts; in contrast, they were negatively associated with the tertiles of scores of lunches, while carbohydrates were positively associated with the lunch scores but negatively associated with breakfast scores.

In breakfasts, whole grains, vegetables and fruits increased across tertiles of meal scores, while sugar-sweetened beverages decreased. The increasing trend for vegetables was seen for lunch and supper as well. For sugar-sweetened beverages, we saw a very significant decrease between tertiles T1 and T2 in all cases, while for fruits we observed a steep increase from tertile T2 to tertile T3.

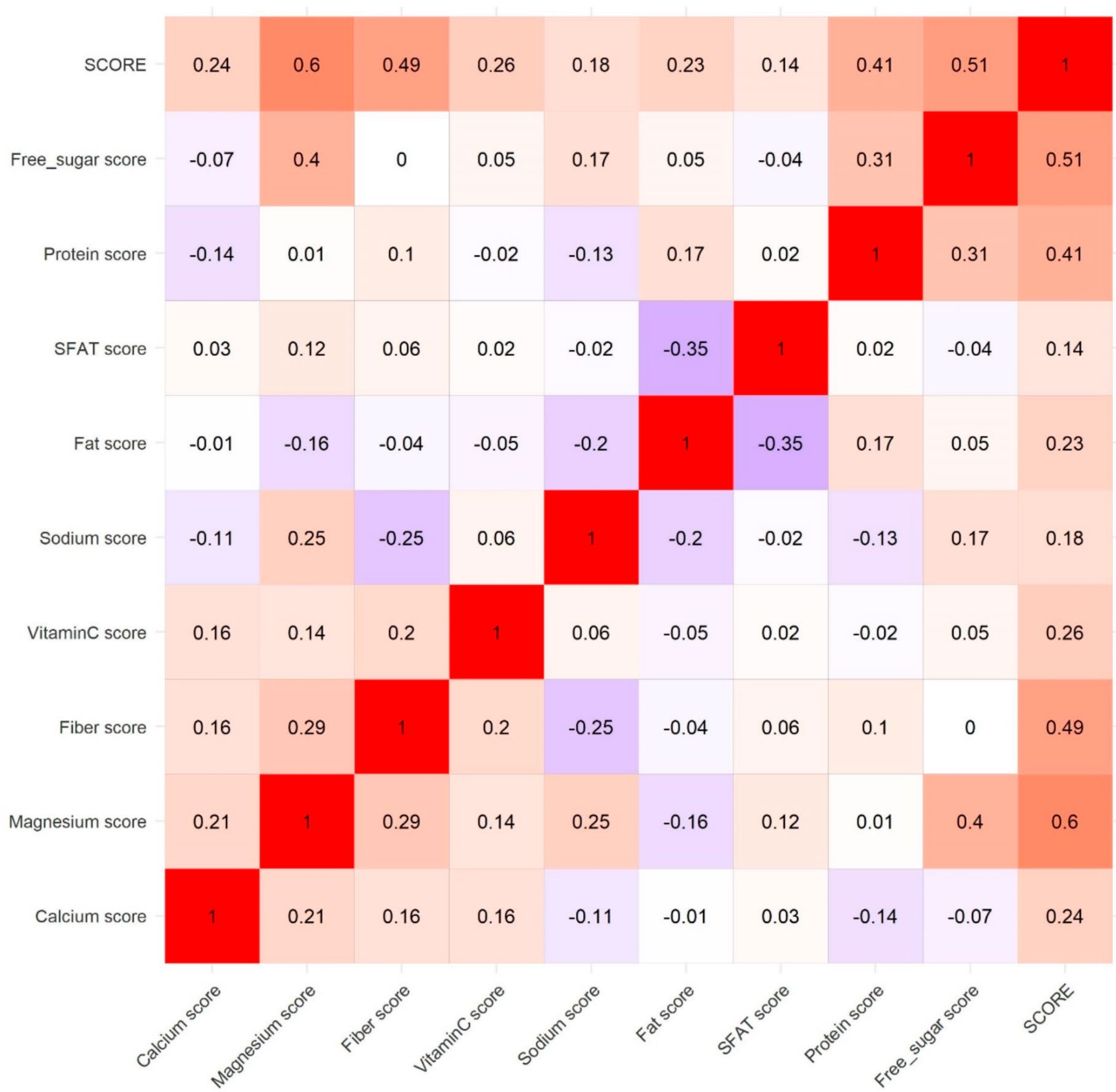


Fig. 4 Spearman correlations between the total score (top line) and the individual nutrient scores, based on the 69,923 meals from the ENNS. The total score is highly correlated with the score for magnesium

Table 3 Spearman correlations between energy and the score, by meal type. All p-values were significant

	AM snack, $N = 3461$	breakfast, $N = 19{,}011$	late night snack, $N = 727$	lunch, $N = 18{,}899$	PM snack, $N = 7971$	supper, $N = 19{,}154$
Correlation	0.24	0.39	0.21	-0.13	0.19	-0.08

Discussion

We developed a score to assess the nutritional quality of meals and applied it to the meals consumed by 19,623 Filipino adults. The average meal score overall was 46 out of 100, with main meals (breakfast, lunch, supper) achieving the best scores compared to snacks.

From the literature [13], it is known that the nutrients listed below are typically under-consumed by a vast majority of Filipino adults: calcium (95–98% prevalence of inadequacy), iron (97–99%), vitamin C (96–98%), vitamin A (54–56%), riboflavin (86–91%), folate (89–90%), thiamin (73–89%), total fat (55–67%). In addition, mean consumption of dietary fiber, ranging from 7.6 to 10.1 g, is far below the recommended nutrient intake of 20–25 g/day for adults. Accordingly, in our data, calcium, fiber, vitamin C and total fat were found to have the lowest scores, showing that content in meals were outside the respective healthy ranges. Scores for sodium, free sugars and SFA were generally high in the ENSS data, with a median value of 100. Comparable results were

Table 4 Content of nutrients and food groups by tertiles of meal scores. Values are mean (SD). High values of standard deviations are due to meals with low calories, and hence high densities. A Kruskal-Wallis test was applied to each row and resulted in a highly significant p-value ($p < 2.2e\text{-}16$). Different letters indicate statistically significant pairwise comparisons (Dunn test, $p < 0.05$). SSB = Sugar-sweetened beverages

Breakfast	Tertile T1: [10, 38] (*N* = 6337)	Tertile T2: [39, 48] (*N* = 6337)	Tertile T3: [49, 100] (*N* = 6337)
Calcium (mg/2000 kcal)	340[a] (3380)	362[b] (388)	476[c] (391)
Carbohydrates (g/2000 kcal)	410 [a] (78.4)	384[b] (57.3)	369 [c] (52.8)
Total fat (g/2000 kcal)	22.6[a] (28.3)	23.5[b] (22.0)	29.8[c] (19.2)
Fiber (g/2000 kcal)	5.35[a] (4.93)	7.21[b] (6.69)	12.6[c] (9.29)
Free sugars (g/2000 kcal)	142[a] (111)	42.6[b] (76.2)	32.9[c] (56.5)
Iron (mg/2000 kcal)	7.90[a] (69.3)	8.47[b] (9.44)	10.6[c] (8.05)
Magnesium (mg/2000 kcal)	100[a] (103)	190[b] (156)	239[c] (129)
Potassium (mg/2000 kcal)	2020[a] (1100)	1510[b] (1920)	1600[c] (981)
Protein (g/2000 kcal)	39.5[a] (24.3)	63.1[b] (25.2)	64.0[c] (23.7)
Saturated Fat (g/2000 kcal)	9.28[a] (13.3)	10.8[b] (11.6)	11.9[c] (9.00)
Vitamin A (µg/2000 kcal)	133[a] (395)	254[b] (477)	422[c] (559)
Vitamin C (mg/2000 kcal)	1.77[a] (9.00)	4.46[b] (37.5)	13.6[c] (39.4)
Vitamin D (µg/2000 kcal)	0.91[a] (3.98)	3.79[b] (6.80)	5.04[c] (11.0)
Vitamin E (mg/2000 kcal)	1.53[a] (5.19)	2.35[b] (3.63)	3.08[c] (3.39)
Zinc (mg/2000 kcal)	3,24[a] (2.89)	5.34[b] (2.48)	6.39[c] (3.48)
Whole grains (g/2000 kcal)	3.41 [a] (28.2)	4.64 [b] (33.2)	27.2 [c] (98.4)
Vegetables (g/2000 kcal)	5.55 [a] (42.0)	23.6 [b] (140)	88.9 [c] (205)
Fruits (g/2000 kcal)	1.27 [a] (42.1)	7.01 [b] (139)	7.85 [c] (97.3)
SSB (g/2000 kcal)	5.92 [a] (5.96)	0.982 [b] (1.59)	0.626 [c] (1.37)

Table 5 Content of nutrients by meal score tertiles. Values are Mean (SD). Pairwise comparisons between groups gave statistically significant differences (Dunn test, $p < 0.05$), except for saturated fat, free sugars and vitamin D. A Kruskal-Wallis test was applied to each row and resulted in a highly significant p-value ($p < 2.2e\text{-}16$)

Lunch	Tertile 1 [10, 45] (*N* = 6300)	Tertile 2 [46, 53] (*N* = 6300)	Tertile 3 [54, 95] (*N* = 6300)
Calcium (mg/2000 kcal)	416 [a] (5830)	301 [b] (202)	402 [c] (272)
Carbohydrates (g/2000 kcal)	367 [a] (82.1)	370 [b] (55.8)	382 [c] (62.8)
Total Fat (g/2000 kcal)	25.1 [a] (31.2)	24.3 [b] (18.7)	22.4 [c] (20.3)
Fiber (g/2000 kcal)	7.12 [a] (7.88)	7.71 [b] (4.78)	16.6 [c] (9.84)
Free sugars (g/2000 kcal)	7.94 [a] (33.2)	1.76 [b] (10.8)	1.66 [b] (12.9)
Iron (mg/2000 kcal)	10.7 [a] (120)	8.16 [b] (3.18)	9.41 [c] (3.93)
Magnesium (mg/2000 kcal)	190 [a] (135)	201 [b] (65.8)	302 [c] (137)
Potassium (mg/2000 kcal)	1220 [a] (1000)	1260 [b] (650)	1900 [c] (921)
Protein (g/2000 kcal)	76.0 [a] (34.1)	75.2 [b] (29.8)	67.9 [c] (33.3)
Saturated Fat (g/2000 kcal)	10.8 [a] (14.7)	10.8 [a] (9.10)	8.86 [b] (9.21)
Vitamin A (µg/2000 kcal)	237 [a] (665)	251 [b] (577)	457 [c] (555)
Vitamin C (mg/2000 kcal)	6.25 [a] (56.5)	7.57 [b] (18.6)	23.4 [c] (31.5)
Vitamin D (µg/2000 kcal)	4.71 [a] (9.89)	4.82 [a] (11.1)	4.38 [c] (12.5)
Vitamin E (mg/2000 kcal)	2.02 [a] (2.43)	2.18[b] (2.11)	2.31[c] (2.30)
Zinc (mg/2000 kcal)	6.68[a] (4.41)	6.38[b] (3.07)	7.15[c] (3.91)
Whole grains (g/2000 kcal)	4.62 [a] (39.8)	3.42 [b] (30.8)	26.5 [c] (108)
Vegetables (g/2000 kcal)	39.5 [a] (293)	62.6 [b] (186)	223 [c] (296)
Fruits (g/2000 kcal)	5.09 [a] (79.6)	4.24 [a] (33.1)	12.1 [b](85.8)
SSB (g/2000 kcal)	0.30 [a] (1.45)	0.05 [b] (0.43)	0.03 [b](0.39)

reported at the level of diets [1], where added sugars, sodium and oils and fats achieved the highest scores as components of the Philippines Healthy Eating Index.

PCA suggested that the score is a truly multi-dimensional construct and could not be explained by a latent lower-dimensional subspace. The practical relevance is that the variability of the score could not be explained by a smaller number of variables, so that the proposed weighting is, in a sense, optimal. The correlation matrix showed both positive and negative interactions between the individual components of the score. The scores for total fat and saturated fat were negatively correlated ($\rho = -0.35$), although the respective nutrient densities are positively correlated (not shown); this might be explained by the different ways they are scored: low amounts of SFA are not penalized by the score, while total fat below the AMDR receive a low score, and as noted above fat is under-consumed by a significant proportion of Filipino adults.

The correlation of the score with the caloric content of the meal varied between meal types. Since the score is based on nutrient densities, it is not directly driven by the amount of energy. A significant correlation of the score with energy therefore suggests a relationship between the total energy of the meal and its composition.

Interestingly, an association between energy and nutritional quality was previously reported [12] in the context of breakfast in the Philippines, where the NRF9.3 score was used.

The overall meal score was positively associated with the content of vitamins A, D and E, which are not included in the calculation of the score. Therefore, even if based on an input of a limited set of relevant nutrients, and only one vitamin, the score may still be predictive of the intakes of other essential nutrients. Some families of nutrients, like amino acids, were not available to us and a more extensive database would be needed to assess the association with a broader range of nutrients. For certain nutrients, such as iron, a positive association was seen only for some meal types (breakfast), which probably reflects different food choices, and in particular fortified foods like breakfast cereals. Furthermore, the density of free sugar was positively associated with the score at breakfast, but negatively associated in the case of lunch and dinner. This could be a consequence of higher intakes of sugared cereals and fruit juices for breakfast. Likewise, the scores were generally associated with the content of vegetables, whole grains, fruits and sugar-sweetened beverages.

Meals in the exemplary menu plans scored significantly higher than the meals reported in the ENNS.

Table 6 Content of nutrients by meal score tertiles. Values are Mean (SD). Pairwise comparisons between groups gave statistically significant differences (Dunn test, $p < 0.05$), except for saturated fat, potassium and vitamin D

Supper	Tertile 1 [10, 45] (N=6385)	Tertile 2 [46, 51] (N=6384)	Tertile 3 [52, 93] (N=6385)
Calcium (mg/2000 kcal)	349 [a] (1580)	313 [b] (302)	422 [c] (326)
Carbohydrates (g/2000 kcal)	354 [a] (90.9)	370 [b] (58.0)	379 [a, b] (64.3)
Total fats (g/2000 kcal)	28.5 [a] (33.7)	23.1 [b] (18.3)	26.5 [c] (20.6)
Fiber (g/2000 kcal)	6.80 [a] (7.66)	7.22 [b] (5.14)	13.6 [c] (9.15)
Free sugars (g/2000 kcal)	7.58 [a] (33.3)	1.46 [b] (9.85)	1.62 [c] (9.15)
Iron (mg/2000 kcal)	8.50 [a] (7.57)	8.29 [b] (3.45)	9.46 [c] (4.46)
Magnesium (mg/2000 kcal)	189 [a] (132)	198 [b] (85.6)	271 [c] (126)
Potassium (mg/2000 kcal)	1270 [a] (907)	1220 [b] (764)	1730 [c] (976)
Protein (g/2000 kcal)	80.2 [a] (37.1)	78.4 [b] (32.2)	71.8 [c] (36.3)
Saturated Fat (g/2000 kcal)	12.1 [a] (16.0)	10.1 [b] (9.03)	10.3 [b] (9.14)
Vitamin A (μg/2000 kcal)	259 [a] (637)	240 [b] (378)	453 [c] (551)
Vitamin C (mg/2000 kcal)	5.39 [a] (54.4)	5.85 [b] (25.3)	19.3 [c] (31.3)
Vitamin D (μg/2000 kcal)	5.00 [a] (9.88)	4.97 [b] (11.8)	5.19 [a] (13.5)
Vitamin E (mg/2000 kcal)	2.02 [a] (2.43)	2.18 [b] (2.11)	2.31 [c] (2.30)
Zinc (mg/2000 kcal)	6.74[a] (4.20)	6.35[a] (2.95)	7.53[b] (2.10)
Whole grains (g/2000 kcal)	6.26 a (46.3)	4.61 (57.2) [b]	27.9 [c] (105)
Vegetables (g/2000 kcal)	30.9 [a] (214)	42.4 [b] (148)	169 [c] (322)
Fruits (g/2000 kcal)	4.74 [a] (63.7)	4.66 [a] (91.6)	11.4 [b] (87.4)
Sugar-sweetened beverages	0.263 [a] (1.53)	0.028 [b] (0.303)	0.036 [b](0.400)

Importantly, the menu plans and the score were developed independently from each other. The menu plans are nutritionally balanced with high adherence to the dietary guidelines, while the average diet in the adult Filipino population is known to be poorly aligned with the guidelines [24]. This analysis provides some reference values for interpreting the scores: even if the scores range theoretically from 0 to 100, we rarely observed meals scoring 100, and values around 75 should be considered as being in the high range, based on the values we observed in menu plans designed according to guidelines.

In summary, the proposed score was able to distinguish between meals from diets that are known to be nutritionally inadequate, and scores from diets designed according to the nutritional guidelines. It showed good correlation with the content of some nutrients not included in the calculation, and with some food groups.

The evaluation of the Filipino diet using the Phil-HEI showed that there is a need for an improvement of the population's diet quality [1]. Our study supports the fact that nutritional guidance to improve the quality of meals may be an actionable way to help people to achieve such an improvement.

Gorgulho et al. [10] developed a score for main meals that was based on a mixture of food groups and nutrients. This score was validated on dietary intake data from Brazil and UK. Their approach was to design the score to follow international guidelines, and they used actual portions consumed as a basis for scoring, as opposed to our density approach, which is agnostic to energy requirements, not known in practice,

A limitation of this study is that we used only the first day of recall from the dietary survey, which might not represent faithfully the usual intakes, and intakes of sporadically consumed foods might have been under-estimated. However, the primary focus of our analysis was the correlation between the quality of meals and the quality of daily intakes, rather than the estimation of habitual intakes. On the other hand, the menu plans covered 2 weeks of diet, mimicking a realistic day-to-day variability, and we observed a consistent agreement of diet quality and meal quality. Also, we did not include any association with health outcomes or anthropometrics, given the cross-sectional nature of the data. Finally, most participants only reported main meals, so that snacks and late-night meals may be underreported.

Conclusions

The use of tools to estimate nutritional balance of meals can encourage healthier cooking and eating habits, which may positively impact the overall health status. We developed a score to assess the nutritional quality of meals, tailored to the adult Filipino population, and assessed it against local dietary guidelines. The proposed algorithm is easy to implement and can be used to promote the consumption of nutrient-dense meals.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40795-024-00954-7.

Supplementary Material 1

Author contributions

FM was responsible for study conceptualization, formal analysis and visualization. FM and NS were responsible for result validation. RP and RC were responsible for funding acquisition and project administration. IA and EF were responsible for data collection and data curation. All authors were responsible for manuscript drafting and critical review.

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Data availability

The data that support the findings of this study are available from DOST-FNRI but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of DOST-FNRI.

Declarations

Ethics approval and consent to participate
This study was done on data collected from the Philippines Extended National Nutritional Survey, which was ethically conducted in accordance with the declaration of Helsinki, guided by the Council for International Organizations of Medical Sciences' (CIOMS) Ethical Guidelines for Biomedical Research Involving Human Subjects and the National Guidelines for Biomedical and Behavioural Research, and was approved by the Philippine Department of Science and Technology - Food and Nutrition Research Institute (DOST-FNRI) Institutional Ethics Review Committee (FIERC) with registry number FIERC-2017-017. The participants were briefed and oriented about the objectives of the study and the data to be collected. Participation in the study was voluntary, and interested participants were asked to sign the informed consent form (ICF). They were told that they could withdraw their participation from the study at any time without any prejudice. Anonymized data analysis was performed in collaboration with DOST-FNRI.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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