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ORIGINAL CONTRIBUTION

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The SHED Index: a tool for assessing a Sustainable HEalthy Diet

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Abstract

Purpose Promoting sustainable diets through sustainable food choices is essential for achieving the sustainable development goals set by the United Nations. Establishing a practical tool that can measure and score sustainable and healthy eating is highly important.

Methods We established a 30-item questionnaire to evaluate sustainable-dietary consumption. Based on the literature and a multidisciplinary advisory panel, the questionnaire was computed by principal component analysis, yielding the Sustainable-HEalthy-Diet (SHED) Index. A rigorous multi-stage process included validation in training-verification sets, across recycling efforts, as an indicator of environmental commitment; and validation across the proportion of animal-protein consumption, as an indicator of adherence to a sustainable and healthy dietary-pattern. The EAT-Lancet reference-diet and the Mediterranean-Diet-score were used to investigate the construct validity of the SHED Index score. Reliability was assessed with a test–retest sample.

Results Three-hundred-forty-eight men and women, aged 20–45 years, completed both the SHED Index questionnaire and a validated Food-Frequency-Questionnaire. Increased dietary animal-protein intake was associated with a lower SHED Index total score ($p < 0.001$). Higher recycling efforts were associated with a higher total SHED Index score ($p < 0.001$). A linear correlation was found between the SHED Index score and food-groups of the Eat-Lancet-reference diet. A significant correlation was found between the Mediterranean-Diet-score and the SHED Index score ($r = 0.575$, $p < 0.001$). The SHED Index score revealed high reliability in test–retest, high validity in training and verification sets, and internal consistency.

Conclusion We developed the SHED Index score, a simple, practical tool, for measuring healthy and sustainable individual-diets. The score reflects the nutritional, environmental and sociocultural aspects of sustainable diets; and provides a tangible tool to be used in intervention studies and in daily practice.

Keywords Sustainable nutrition · Healthy eating · Dietary patterns

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Introduction

The continued rise in diet-related chronic diseases, the growing contribution of food systems to climate change [1] and the reciprocal threat of climate change to food systems [2] call for a shift towards sustainable diets [3]. Sustainable diets are defined as diets that improve health, have low environmental impacts, and are economically accessible and culturally acceptable [4]. Shifting food preferences towards such diets has been proposed as an important strategy to promote sustainability across the food system. The European Commission's communication "A Clean Planet for All" outlined the importance of changing consumers' food preferences to promote health, and to reach greenhouse gas emission (GHGE) neutrality by 2050 [5]. Moreover, promoting sustainable diets through sustainable food choices is essential for achieving many of the sustainable development goals set by the United Nations [6].

Sustainable diets are most often defined as plant-based diets because they decrease both food-related environmental impacts and adverse health outcomes [7]. Shifting consumers towards plant-based diets is therefore an effective strategy to reduce overall environmental pressures while increasing public health [3, 7]. The EAT-Lancet commission recently defined a reference 'planetary health diet', and outlined a combination of food groups and ranges of food intakes that would optimize human health and the environment [3]. Local interpretation of the recommended planetary health diet is mandatory to ensure adaptation; and should reflect the culture, geography and demography of individuals, as well as of populations. In this respect, the most suitable interpretation of sustainable diets in Israel is the Mediterranean diet. This diet is recognized as both healthy and sustainable [8], and encompasses the locality of foods, waste reduction and cultural aspects [9]. However, existing tools for assessing the Mediterranean diet mainly capture food consumption per se, and do not account for other dimensions.

The path towards a more sustainable diet should be monitored quantitatively. Therefore, a tool is needed to measure and track individual preferences. While the concept of evaluating healthy diets is well established, it has seldom been combined with sustainability aspects [10, 11]. Most studies have focused on either healthy *or* environmentally friendly food consumption. Further, environmental indices usually focus on only a few parameters, such as purchasing local foods, consuming organic produce and reducing meat consumption while ignoring other important factors. For example, indicators, such as food waste and use of bottled water, are rarely taken into account [12, 13]. In addition, other dimensions of sustainability, such as sociocultural, and economic, are often not included [4]. Few studies have attempted to integrate all dimensions [12, 14]. Seconda et al. suggested an individual consumption index, which integrates all dimensions into a composite indicator [15]. However, the assessment method they used requires various sources of information that are not always accessible to consumers or nutrition practitioners.

Establishing a concise and practical assessment tool that can both measure *and* score sustainable and healthy eating patterns is paramount to shifting consumer preferences towards sustainable diets. Since local foods and eating habits are primary components of such diets, the tool must account for local eating patterns and should be flexible and possibly modular, and thus adjustable to various regions and societies.

Here, we outline a methodology to evaluate and score self-reported consumption patterns, identify multidimensional aspects of an individual's healthy and sustainable diet, and serve as a practical tool.

Methods

The research tool

We assembled a multidisciplinary advisory panel, which included experts from environmental science, nutrition, agriculture, public health, risk-assessment, methodology and consumer behaviour. Questionnaires and studies regarding healthy and/or sustainable diets were extracted from the literature [13, 16–18] for the panel to review. Moreover, a literature review of eating habits related to sustainability was conducted and additional components were derived. The components included overall dietary consumption; consumption of sweetened beverages and bottled water; consumption of ultra-processed food and plant-based foods; purchase of organic food and food consumerism, including food waste and domestic waste streams. Items and queries to be included in the preliminary questionnaire were initially selected according to the feasibility of measuring them at the individual level, and whether they were related to at least one of the dimensions of a sustainable diet (nutrition, sociocultural aspects, environment, economy). Our panel agreed on most issues. However, some issues were debated regarding their application to Israeli society. The value of consuming organic food in Israel is an example. According to most questionnaires in the literature, purchasing and consuming organic food is perceived as a measure of sustainable eating. Yet, in light of the limited agricultural land per person and the potentially lower organic yields in Israel [19], some panelists argued that organic farming should not necessarily be considered as sustainable. Ultimately, the questionnaire did include items regarding consumption of organic foods. The rationale was that while the environmental contribution and health merits are debatable, the consumption of organic foods has social value, by encouraging local smallholders' agriculture and closer contact between farmers and consumers. Another debatable issue was how to refer to fresh food packaging in Israel's warm climate. In Israel, fruits and vegetables are sold in bulk or in packaged servings. Plastic packaging causes environmental and health damage [20]; yet, since food is kept fresh longer in these packaging, it might decrease food waste. Here, the panel decided not to include items regarding food packaging, due to the lack of conclusiveness regarding its benefit or harm to health and the environment.

Sustainability practices presented the panel with greater challenges than did items regarding healthy nutrition. After reviewing the questionnaires to date, and discussing various aspects of sustainability, items regarding the following were included: make compost, consume local food, reduce food waste, purchase food in locations other than the supermarket (from a local grocery, farmer's market, farm, self-production), drink tap rather than bottled water, and recycle. The frequency of consuming ready meals, e.g., frozen or take-away, was considered for both the healthy and sustainable dimensions, as was the consumption of sweetened beverages (sugar sweetened and low-calorie beverages). While the contribution of consuming sugar-sweetened beverages to obesity and disease burden is well documented [21, 22], the contribution of low-calorie sweetened beverages is somewhat controversial [23, 24]. We included both types of beverages in the drinking pattern score, since both contribute to the environmental burden, mainly due to the packaging [25]. However, the consumption of sugar-sweetened beverages was attributed more weight in the index.

In addition to purchasing organic food, we inquired about purchasing produce with reduced pesticides and herbicides. In Israel, some produce does not meet organic label requirements, but contains a reduced level of pesticides and herbicides. These products are identified by a label and are less expensive than organic food.

Household recycling efforts and waste sorting were documented when service was available (collection sites or designated bins). As suggested by Goldman et al., recycling efforts reflect environmental commitment in Israel, since this activity is voluntary and without economic incentives [26].

The final 30-item web-based questionnaire was subsequently constructed. (Supplementary file A). Face validity was tested by three experts, to examine whether the questionnaire appears to measure meaningful items, and pretesting of wording was done in a pilot of 10 participants.

In the final version of the questionnaire, responses to the items regarding *sustainable and healthy eating* are recorded on a Likert scale of 1–4. Items are ranked from "Almost never true" to "Almost always true", or "Never" to "Most of the time". Data on consumption of beverages and ready meals are recorded on a scale of six frequencies, from "Never" to "Daily"; and compliance with recycling waste and packaging on a visual analog scale of 100%. Finally, participants are asked to rate the proportion of plant-based food of their entire diet on a 0–100% scale. The questionnaire includes information on demographics, lifestyle, location of food purchase and the frequency of food preparation.

Study population

By social media, emails and phone, we recruited 348 men and women, aged 20–45 years. We approached pre-defined subpopulations, such as vegans and vegetarians; persons identifying as secular, orthodox and ultra-orthodox; rural and urban participants; and persons with various environmental orientations. Using data from the Central Bureau of Statistics in Israel [27], we aimed for a representative sample of these subpopulations. Once achieving the representative sample for a specific sector, further respondents from this sector were excluded during the phone interview. Participants received the equivalent of 10 USD for completing the questionnaire.

The food frequency questionnaire

To validate the food consumption items, we used a food frequency questionnaire (FFQ) that was developed for the Israeli population. The development and validation process of this questionnaire were described in detail elsewhere [28, 29]. Briefly, the FFQ includes 115 food items with nine frequency options, ranging from "never or less than once monthly" to "six or more times daily." The questionnaire is semi-quantitative, and a standard portion size is described for each food item. The portion size estimates are based on information from the Israel Ministry of Health. Participants are requested to report their average frequency consumption during the past year. The questionnaire was self-administered electronically, thus ensuring completeness of the data, as a participant cannot complete the questionnaire if an item is not answered.

Mediterranean-Diet score

Based on the FFQ fulfilled by the participants, we calculated adherence to the Mediterranean diet, according to the 9-point score created by Trichopolou et al. in 2003 [30]. For each of the nine components, with the exception of alcohol, a value of 0 or 1 is assigned. The units of measurements are serving size and the sex-specific medians of intake of the sample are used as cut-off points. One point is assigned for consumption that is above the median for each of the six protective components (fatty acid ratio, legumes, grains, fruits, vegetables and fish), and one point is assigned if intake is below the median for the two non-protective components (dairy products and meat). For alcohol, one point is assigned for a mean consumption of 10–50 g/day for men, and 5–25 g/day for women. A score of 9 reflects maximum adherence, indicating that the participant meets all the characteristics of the Mediterranean diet. Based on a sensitivity analysis, we constructed three levels of adherence scores. Low adherence was defined as 0–3 points, medium adherence as 4–6 points and high adherence as 7–9 points.

Demographics and quality of life

Socio-demographic and lifestyle data included age, sex, employment status, marital status, academic education, area of residence (urbanization degree), religious identification, crowding (persons per room), smoking status, level of physical activity and weight status (which was classified into three categories: normal weight, overweight and obese). Most of these variables were classified into binary variables and reported as percentages. Health-Related Quality of Life (HRQOL) was recorded according to the CDC well-being tool and included: 'HRQOL'—unhealthy days, indicating compromised physical or mental health in the last month, and self-rated general health [31].

Reliability of the questionnaire was assessed with a test–retest sample. A subset of 43 participants completed a retest within 3 months from filling the initial questionnaire. For the test–retest sample, a pairwise correlation coefficient matrix of selected items and components was evaluated. Representation of all the pre-defined population segments was preserved. The compliance rate was 94%.

Data collection

The survey data were collected using a web application of Qualtrics software, version XM©. This application reduces missing data. Skipping questions is possible only with pre-definition, and was allowed only regarding items that were decided in advance. Qualtrics and all other Qualtrics product or service names are registered trademarks of Qualtrics (Provo, UT, USA. https://www.qualtrics.com). The data were extracted in a csv format and submitted for statistical analysis.

Statistical analysis

The questionnaire data were filtered through several transformations to generate the working variables and dataset. The main transformations include a sub-score for Healthy Eating, namely the 'HE-score', summarizing 10 heathy-eating elements; and a sub-score for Sustainable Eating, namely the 'SE-score', summarizing 7 sustainable-eating elements. Transformations were performed such that the minimum score would be 0, and the negative items would be reversed. These sub-scores were defined as the summation of items from the same dimension. Other sub-scores were computed by attributing different weights for each frequency of consumption, as described here.

The 'Water Score' describes the source of drinking water: a higher score indicates frequent use of tap water, whereas a lower score indicates frequent use of bottled water. The 'Ready Meals' score includes items regarding eating out or eating frozen or refrigerated meals; a higher score indicates eating more home-cooked meals. The 'Soda Score' evaluates the frequency of consuming sugar and artificially sweetened beverages, with more weight attributed to sugar sweetened beverages; a higher score indicates lower frequency. Finally, a higher score of 'BFV' (Buy-Fruits-and-Vegetables: where do you buy your fruits and vegetables?) indicates the purchase of local rather than not local fruits and vegetables purchasing. The purposes of these sub-scores were to explore separately each dimension of the total score, to characterize the study population, and to enable index adaptations and adjustments.

The total SHED Index score was computed by submitting to a principal component analysis (PCA), the 17 items of HE [Healthy] and SE [Sustainability], together with the items of water score, soda, recycling habits (percent recycling), BVF score, organic food consumption and ready meals; and the proportion of the diet that is plant-based. This was done with the oblimin rotation, which does not force the resulting factors to be orthogonal. Prior to submission to the PCA, all the variables were Z-transformed. Only items with less than 5% missing data were included in the analysis, and mean substitution was used for the missing values of the items included. Based on the scree plot, all factors with eigenvalues above 1.0 were extracted. The final components included only items with loading above 0.3. The component structure was displayed in a diagram together with the loading. Prior to PCA, a 50% training set was randomly drawn from the data and the PCA was run only on the training set. The results were then verified on the remaining 50% of the data, the 'verification set'.

The PCA resulted in six components that were summed to a final score. The final SHED Index is the standardized sum of these six components; the mean is 60 and the standard deviation is 10.

A number of methods were used to evaluate the reliability and validity of the components. First, the components were derived on a training subset of the data. They were then verified using the verification subset of the data: once as a within component correlation, and subsequently in comparison to the HE and SE sub-scores of the questionnaire. Finally, a re-test sample was correlated with the initial sample. The within-component matrices of the training and verification sets showed similar structures. In both data sets, positive correlations were found between the first four components. In addition, all six components correlated negatively with Unhealthy and non-sustainable behaviour. Good internal consistency was found, with Cronbach's alpha coefficient ranging from 0.60 to 0.86 for each of the six principal components (Tables 2–5S, supplementary file B). The score was further validated across recycling efforts, as an indicator of environmental commitment; and across percentage of animal protein of the total protein consumption, as an indicator of adherence to a sustainable and healthy dietary pattern [32]).

Finally, we used the EAT-Lancet reference diet and the Mediterranean diet score to further investigate the construct validity of the SHED Index score. Both diets are considered healthy and sustainable. However, the Mediterranean diet covers certain aspects, such as affordability better than the EAT-Lancet; and the EAT-Lancet covers environmental aspects better than the Mediterranean diet [8, 33, 34]. We compared the consumption of each food group across SHED Index-score tertiles, with the recommended reference planetary plate food groups (EAT-Lancet reference diet). In addition, we examined the correlation between the SHED Index score and the Mediterranean diet score (as continuous variables); and evaluated the SHED Index score across the three levels of adherence to the Mediterranean diet score (low, medium and high adherence).

We used Pearson correlations to examine relations between continuous variables of the SHED Index score and the sub-scores. We used the ANOVA test to evaluate associations of tertiles of the SHED Index score with socio-demographic variables and with the EAT-Lancet reference-diet food groups; and to evaluate associations between tertiles of the SHED Index score and adherence to the Mediterranean diet. We used R base [35] and ggplot2 [36] for analysis. The R programs for transformation and analyses are available per request.

Sampling and sample size considerations

Although this was a digital reach-out sample, we aimed that it would be representative of the general population. Thus, the sample included an equal ratio of men and women from cities and villages of secular and orthodox communities, with a range of socioeconomic status. Based on demographic distribution in Israel [37], we included 30% religious participants (both religious and ultra-orthodox) at an equal ratio of men and women. The participants defined their degree of religiosity, and we stratified the analysis by religious and secular affiliation. Socioeconomic status was classified by residence and by the number of rooms per person. Once achieving the representative sample of a given sector (for example, secular women), we excluded respondents from the same sector.

The sample size did not meet formal type I and II errors as there was no standard hypothesis testing. Nevertheless, the sample size of $n = 300$ allowed the algorithm conversion with no collinearity. Moreover, this number permitted reasonable testing and verification of subsets for development of the model.

Results

The study included 348 participants. Baseline characteristics of the study population are presented in Table 1. The participants were stratified by tertiles of the SHED Index score. The mean of the total SE-score was 5.9 ± 4.4 of 20, and of the total HE-score 15.4 ± 6.4 of 30. Participants in the lower tertile of the SHED Index score were younger, more often men, more often with overweight or obesity, and with lower general health (as self-ranked in HRQOL4). Participants in the upper tertile of the SHED Index score were more often secular, single, and vegetarian or vegan. Compared to the general population, participants were more educated and with better healthy behaviours (Table 1).

Principal component analysis

The PCA resulted in six components, the total variance explained was 44%. Four items were not loaded by the algorithm on any of the components. These items were: purchase of local products, recycling bottles, eating home-cooked meals and the source of drinking water ('water score'). We named the components according to the main item each factor represented, as follows: plant-based diet (11.4%), Organic awareness (7.7%), drinking habits (6.7%), healthy dietary consumption (6.6%), consumerism (5.3%), and unhealthy and non-sustainable behaviour (5.1%) (Fig. 1S. supplementary file B). Positive correlations within components were found between the components: plant-based diet and Organic awareness ($r = 0.3$), and between the components: Healthy dietary consumption and Drinking habits ($r = 0.3$). A negative correlation was found of Healthy dietary consumption with Unhealthy and non-sustainable behaviour ($r = -0.4$) ($p < 0.01$ for all correlations) (Fig. 1S. supplementary file B).

Individual items and sub-score characteristics of the SHED Index questionnaire

The Likert scale scores of the individual items are summarized in Fig. 1. For the items: 'Prefer self-cooked meals', 'Prefer home-cooked meals', 'Eat food prepared days before', 'Drink mainly water' and 'Limit sweets and soft drinks', the mean ranks were above 3, thus representing high-frequency behaviours—often or daily. The items: 'Consume organic products', Make compost', 'Drink mainly bottled water' and 'Consume frozen ready meals' had mean ranks less than 1.5, representing low frequency behaviours.

The sub-score characteristics and their correlations with the total SHED Index score are presented in Table 2. The HE and SE sub-scores correlated more strongly than the other sub-scores with the total SHED Index score ($r = 0.94$ and 0.86, respectively, $p > 0.05$).

Most of the participants reported purchasing their fruits and vegetables at a supermarket, a local grocery or a green grocer (mean rank $\pm$ SD: 3.1 ± 0.9, 2.2 ± 0.9 and 2.1 ± 0.8, respectively). Only rarely did participants report purchasing their fruits and vegetables directly from a farmer (mean $\pm$ SD: 1.3 ± 0.6 and 1.3 ± 0.6, respectively) (Table 6S supplementary file B).

We examined recycling efforts as an indicator of environmental commitment. Participants with available

Table 1 Characteristics of the study population according to the Sustainable and Healthy Eating (SHED) Index-score tertiles

	Tertiles of the SHED Index[a]			Total ($n=348$)	p[b]	Population[c]
	1st Tertile ($n=116$)	2nd tertile ($n=116$)	3rd tertile ($n=116$)			
Age (years)	30.98 ± 9.17	30.17 ± 8.11	33.73 ± 10.94	31.62 ± 9.57	0.012	
Sex (women)	47 (40.52)	61 (52.59)	71 (61.21)	179 (51.44)	0.007	
Married	55 (47.41)	52 (44.83)	47 (40.52)	154 (44.25)	0.007	45%
Employed	69 (59.48)	66 (56.9)	69 (59.48)	204 (58.62)	0.898	67%
Secular	71 (61.21)	81 (69.83)	95 (81.9)	247 (70.98)	0.002	70%
Urbanization						
City	62 (53.45)	61 (52.59)	72 (62.07)	195 (56.03)	0.434	60%
Peripheral city	23 (19.83)	20 (17.24)	15 (12.93)	58 (16.67)		
Village/community settlement	30 (25.86)	34 (29.31)	30 (25.86)	94 (27.01)		
Person/room	0.95 ± 0.31	0.89 ± 0.32	0.88 ± 0.33	0.91 ± 0.32	0.172	0.8
Education (academic)	81 (69.83)	94 (81.03)	91 (78.45)	266(76.44)	0.102	46%
PA minutes/week	177.82 ± 131.9	187.86 ± 141.82	185.59 ± 125.12	184.19 ± 132.53	0.890	
Smoking	12 (10.34)	9 (7.76)	15 (12.93)	36 (10.34)	0.443	20%
Poor general health[d]	15 (12.93)	6 (5.17)	4 (3.45)	25 (21.55)	0.011	
Sum of unhealthy days[e]	5.1 ± 6.62	4.57 ± 5.26	5.71 ± 6.51	5.12 ± 6.16	0.370	
Weight status[d]						
Normal	69 (59.48)	95 (81.9)	97 (83.62)	261 (75)	< 0.001	
Overweight	39 (33.62)	18 (15.52)	15 (12.93)	72 (20.69)		30.5%
Obese	7 (6.03)	5 (4.31)	3 (2.59)	15 (4.31)		17%
HE score	9.4 ± 3.87	15.46 ± 3.83	21.42 ± 4.59	15.43 ± 6.4	< 0.001	
SE score	3.12 ± 2.31	4.59 ± 2.86	10.05 ± 4.16	5.92 ± 4.37	< 0.001	
SHED Index	49.25 ± 5.1	59.03 ± 2.33	71.73 ± 6.79	60 ± 10.00	< 0.001	
Eating pattern[d]						
Vegetarian/Vegan	4 (3.45)	11 (9.48)	41 (35.34)	56 (16.09)	< 0.001	13%
Flexitarian	5 (4.31)	16 (13.79)	32 (27.59)	53 (15.23)		23%
Omnivore	97 (83.62)	79 (68.1)	33 (28.45)	209 (60.06)		
High animal based diet (paleo, ketogenic, etc.)	13 (11.21)	10 (8.62)	7 (6.03)	33 (9.48)		

SHED Index the total SHED Index score, *PA* physical activity, *HE* healthy eating score (10-items), *SE* sustainable eating score (7 items). Each variable had less than 5% missing values

[a] 1st tertile ≤ 54.92; 2nd tertile 54.93—62.97; 3rd tertile > 62.98. The total score was computed as described in the statistical analysis. The score is standardized with SD = 10 and centered around 60. Data are presented as means ± SD or n (%)

[b] ANOVA or Pearson p value as appropriate

[c] Age matched data [27, 37]

[d] Self-reported

[e] Summary from Health-Related Quality of Life (HRQOL) questions—unhealthy days with compromised physical or mental health in the last month and self-rated general health

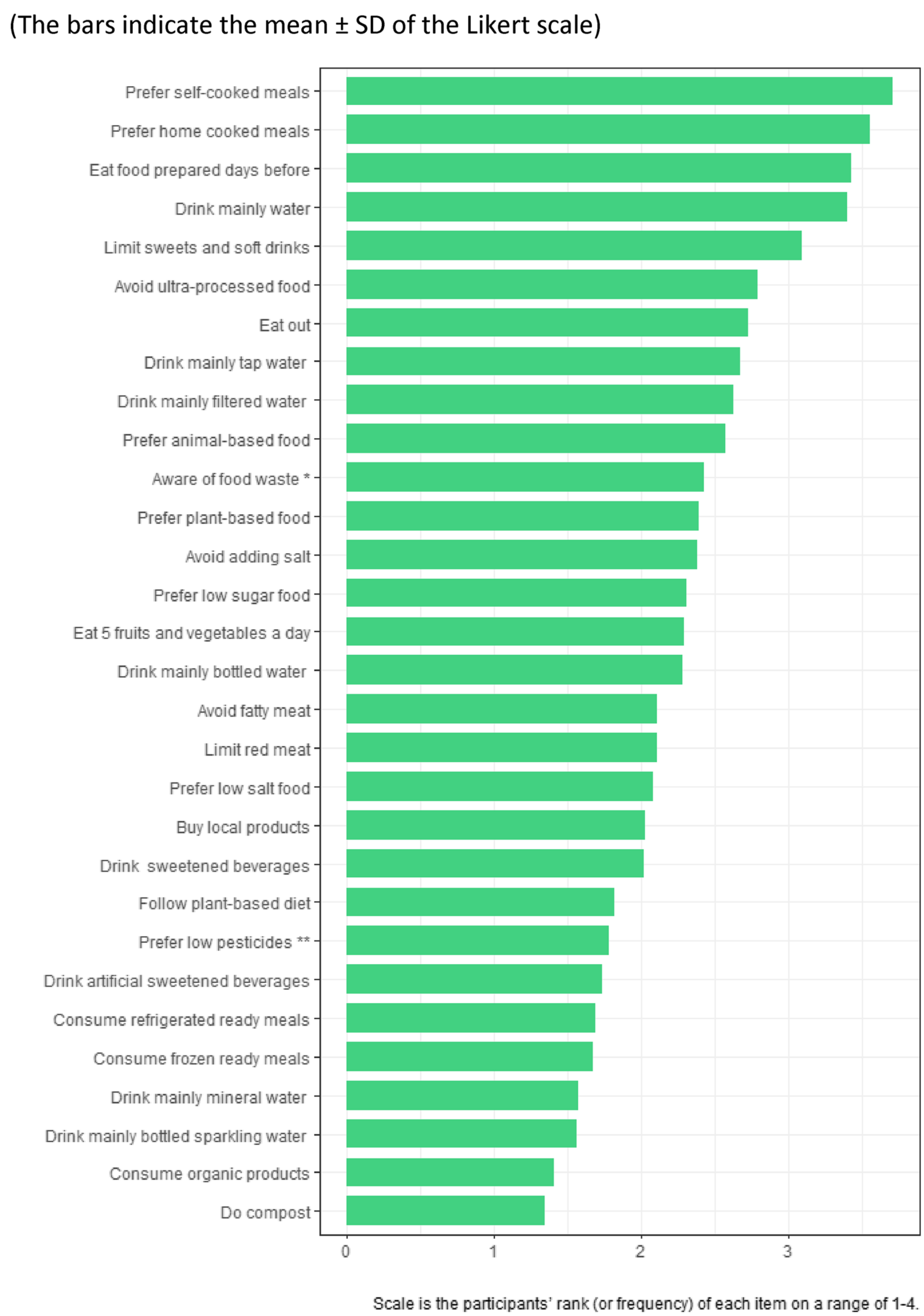
recycling services reported utilizing them 50% or more of the time (Figure 3S, Supplementary appendix B). Recycle bins were mainly available for plastic bottles, while bins for recycling glass and organic waste were rarely available. The reported behaviours were considered indicators for validating the total SHED Index score.

Test–retest showed high reliability, as the sample replicated well, with a correlation of above $r = 0.6$ for most of the sub-scores ($p < 0.05$) (Table 5S, supplementary file B).

Validity of the SHED Index score

Strong associations were found between the total SHED Index score and the percent of animal protein intake (derived from the FFQ), and between the total SHED Index score and recycling efforts (demonstrated by a violin plot in Fig. 2). Increased dietary animal-protein intake was associated with a *lower* SHED Index total score

Fig. 1 Items of the Sustainable Eating and Healthy Eating Questionnaire (the bars indicate the mean ± SD of the Likert scale)



($p < 0.001$). Higher recycling efforts were associated with a *higher* total SHED Index score ($p < 0.001$).

Associations of the SHED Index with selected reference diets

For most of the food groups, a linear correlation was found between the tertiles of the SHED Index score and the Eat-Lancet reference diet (Table 3). Greater consumption of fruits, vegetables, legumes and nuts was associated with a higher SHED Index-score tertile. Lesser consumption of dairy, meat, poultry, saturated fats and added sugars was associated with a higher SHED Index-score tertile. All the SHED Index-score tertiles met recommendations for fruit, vegetable and fish consumption of the Eat-Lancet reference diet. Consumption of meat, poultry and eggs demonstrated the highest disparities between the SHED Index score and the Eat-Lancet reference diet; the differences were in the range of 300–600 percent higher than the Eat-Lancet recommendations (Table 3).

Table 2 Characteristics of the sub-scores and their correlations with the SHED Index score

	Mean	SD	Min	Max	Cor[a]
HE	15.4	6.4	0	30	0.94
SE	5.9	4.4	0	20	0.86
BFV location	2.4	0.6	1.0	4.0	0.29
Ready meals	1.7	0.3	−0.1	2.0	0.3
Water	1.3	0.9	−1.0	3.0	0.23
Sodas	7.5	2.1	0	−10	0.51
SHED[b]	60	10	29.8	89.1	

HE healthy eating score (10-items), *SE* sustainable eating score (7 items), *BFV* fruits and vegetable purchasing location—local vs. not-local purchase place, *Ready meals score* consumption of frozen or refrigerated meals vs. home cooked (6 items), Water score: source of drinking water (5 items), *Soda scores* consumption of sugar-sweetened and low-calorie sweetened beverages (2 items), *SHED Index score* the total SHED Index score

[a]Pearson correlation coefficient with SHED score. *all $p < 0.001$

[b]The SHED Index score was calculated by PCA, as described in the statistical analysis section

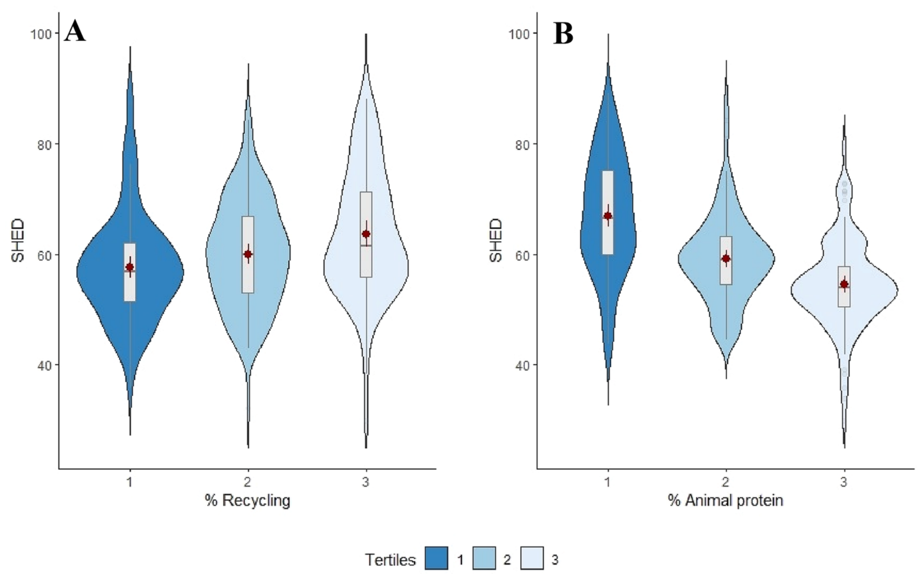
A relatively high correlation was found between the Mediterranean diet score and the SHED Index score (Spearman's correlation coefficient = 0.575, $p < 0.001$). Higher adherence to the Mediterranean diet was associated with a higher SHED Index score (Fig. 3). The mean Mediterranean diet score was 3 in the lowest SHED Index-score tertile, 4 in the middle SHED Index-score tertile and 5 in the highest SHED Index-score tertile.

Discussion

In this study, we described the development of the SHED Index score, which is an integrative, simple and practical index, created to assess both healthy and sustainable diets. The index reflects the nutritional, environmental and sociocultural aspects of individual diets. The SHED Index revealed high reliability in test–retest, high validity in training and verification sets, and internal consistency.

In the absence of a gold standard for sustainable and healthy diets, we used proxy indicators. These included recycling efforts as an indicator of environmental commitment, and the animal protein ratio as an indicator of environmental impact. We also compared the SHED Index to the Mediterranean diet and to the EAT-Lancet reference diet, as indicators of sustainable and healthy diets.

The SHED Index demonstrated high correlation with adherence to the Mediterranean diet. The Mediterranean diet is well established as a healthy diet with a low environmental footprint [9, 38], but it encompasses much more



- Linear regression p-value < 0.001
- The violin plot indicates the distribution.
- The boxplot indicates the lower-median-upper tertile
- The red dot with the interval indicates the mean and standard error.
- Color indicates: A. %recycling: 0-59, 60-95, 95-100 and B. % animal protein: 0-57.5, 57.5-70.5, 70.5-100

Fig. 2 Associations of the total SHED Index score with dietary protein intake (**a**) and the recycling score (**b**)

Table 3 Food groups of the EAT-Lancet reference diet and food groups derived from the food frequency questionnaire, across tertiles of the SHED Index score

	Eat Lancet reference diet (gr)	Tertiles of the SHED Index[a]						Total ($n=348$)		p^b
		1st tertile ($n=116$)		2nd tertile ($n=116$)		3rd tertile ($n=116$)				
		Mean (gr)	% Eat-Lancet	Mean (gr)	% Eat-Lancet	Mean (gr)	% Eat-Lancet	Mean (gr)	% Eat-Lancet	
Grains[c]	**232**	170.87	**73.65**	185.91	**80.14**	208.36	**89.8**	188.41	**81.21**	0.103
Starchy vegetables	**50**	50.25	**100.49**	42.49	**84.98**	37.56	**75.1**	43.40	**86.80**	0.035
Vegetables	**300**	495.66	**165.22**	677.60	**225.87**	925.57	**308.5**	699.97	**233.32**	< 0.001
Fruits	**200**	225.22	**112.61**	299.26	**149.63**	449.57	**224.8**	324.67	**162.34**	< 0.001
Dairy	**250**	654.09	**261.64**	391.28	**156.51**	326.99	**130.8**	456.02	**182.41**	< 0.001
Meat	**14**	85.03	**607.34**	57.97	**414.04**	49.84	**356.0**	64.14	**458.11**	0.005
Poultry	**29**	146.96	**506.75**	112.22	**386.97**	68.49	**236.2**	109.14	**376.35**	< 0.001
Eggs	**13**	48.55	**373.44**	47.53	**365.65**	44.78	**344.4**	46.96	**361.19**	0.938
Fish	**28**	33.72	**120.42**	31.06	**110.94**	25.01	**89.3**	29.93	**106.91**	0.464
Legumes	**75**	49.06	**65.42**	59.42	**79.22**	100.75	**134.3**	69.68	**92.90**	0.001
Nuts	**50**	7.74	**15.47**	11.42	**22.83**	22.21	**44.4**	13.78	**27.56**	< 0.001
Unsaturated fats[d] (gr monounsaturated)	**40**	56.79 (36.12)	**141.97**	52.86 (33.15)	**132.14**	61.65 (38.82)	**154.1**	57.06 (36)	**142.65**	0.22 (0.2)
Saturated fat	**11.8**	32.76	**277.59**	24.50	**207.60**	24.48	**207.5**	27.20	**230.53**	0.005
Added sugars	**31**	40.65	**131.12**	27.71	**89.39**	31.21	**100.7**	33.10	**106.77**	< 0.001
Energy	**2500**	2428	97	2150	86	2364	95	2312	92	0.281

Bold value indicates the comparison to Eat-Lancet reference diet

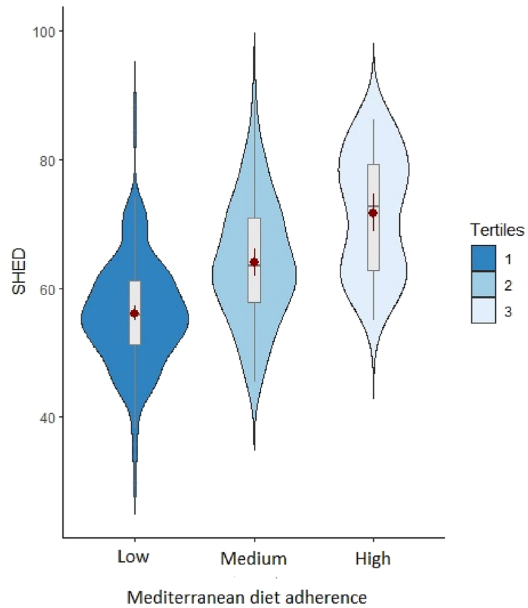
[a]SHED Index score: 1st tertile ≤ 54.92; 2nd tertile 54.93—62.97; 3rd tertile > 62.98

[b]ANOVA test for differences between tertiles

[c]The tertile means represent the total consumption of grains, while the Eat-Lancet reference diet refer to whole grains

[d]Unsaturated fats = mono- and polyunsaturated fats. The values in the brackets indicate the share of monounsaturated fats, which the EAT-Lancet does not refer to, yet is the main source of unsaturated fats in the Israeli diet

Fig. 3 Association between the SHED Index score and adherence to the Mediterranean diet



- ANOVA test, all p<0.001.
- The violin plot indicates the distribution.
- The boxplot indicates the lower-median-upper tertile.
- The red dot with the interval indicates the mean and standard error.
- Color indicates: Low adherence: n=155; Medium adherence: n=116; High adherence: n=77

than just food. The Mediterranean diet was inscribed in the UNESCO Representative List as an Intangible Cultural Heritage of Humanity [39]. Accordingly, the social and cultural attributes of this diet are not manifested only in the specific foods and nutrients included, but also in the manner the food is produced, cooked and eaten [9]. Currently, the Mediterranean diet score accounts for the dietary components alone, without addressing sociocultural aspects, such as frugality and moderation, avoiding food waste, consumption of local products and traditional meals, and appraisal of family and community dining. The SHED Index score captures aspects of the sociocultural merits of the Mediterranean diet, such as local food, minimal food waste and home-cooked meals. Adding dimensions beyond food provides researchers and practitioners additional aspects for assessing the sustainability of an individual's diet.

Overall, the SHED Index score showed good consistency with the EAT-Lancet reference diet. The latter allows flexible application of foods and amounts according to preferences and cultures of different populations [3]. The higher the SHED Index score, the more closely the diet resembled the EAT-Lancet diet. However, despite a significant difference in meat and poultry consumption between the first and the third SHED Index-score tertiles, significant gaps with the EAT-Lancet reference diet were apparent. This might be explained by the relatively high consumption of meat and poultry in Israel, ranked fourth in meat consumption and first in poultry consumption among OECD states [40]. Notably, fruit and vegetable consumption in the SHED Index was relatively high, exceeding recommendations of the EAT-Lancet diet reference across all tertiles. In contrast to data of the Food and Agriculture Organization of the United Nations for Israel, fruit consumption reported in our survey was similar, while vegetable consumption was significantly higher [41, 42]. This discrepancy may be explained in part by the use of the FFQ for dietary assessment, a tool prone to overestimation [43]. Although we compared our results to the EAT-Lancet reference diet, this diet is not considered a dietary guideline for individuals per se. Since the publication of this reference diet, an ongoing debate regarding its healthiness, feasibility and affordability has emerged [34, 44]. Nonetheless, it is accepted as a diet with very low environmental burden, and we considered it as a proxy to a gold standard of a sustainable diet.

The SHED Index score is an integrative simple tool. By including items on dietary intake, consumer habits and eating behaviour it provides important information on habits pertaining to food purchases and handling. To date, only a few studies have implemented a similar approach. Harray et al. [13] developed an image-based mobile food record application to assess sustainability and healthiness of individual diets. Their index includes consumption of specific food groups related to sustainable diets (fruits, vegetables, dairy, eggs, meat, poultry and ultra-processed food), combined with assessment of food waste and individually packaged food. However, their methodology includes 4 days of food records; this requires high compliance of the participants and yields variable motivation [45]. Other studies used nutritional scores that assessed healthy diets and diverse sustainable nutrition scales, yet without a composite measure [16, 46]. Seconda et al. [15] developed a comprehensive index based on a multi-criteria approach, which also provided a composite index for an individual's diet. However, their computed score requires comprehensive integrated measures that are not always accessible, such as household income for food, information regarding land and energy use, and GHGE of food products. This limits the use of the index mainly to research settings. The SHED Index score offers a simple method to capture these dimensions; does not require filling an FFQ or other methods of nutritional assessment; and can easily be used by practitioners interested in incorporating environmental considerations into their dietary recommendations.

Reducing consumption of animal products, especially ruminant meat, has been shown to contribute substantially to reducing GHGEs and improved health [47–50]. Hence, it might be argued that a sustainable diet score should include fewer indices, and focus primarily on animal-product consumption [51]. Indeed, replacing animal-source food items with plant-based items reduces the environmental impact (up to an 84% reduction in GHGEs), improves nutrient consumption and lowers the risk of premature mortality (up to 12% reduction), especially in high- and middle-income countries [7]. However, in our opinion, it is incorrect to rely on a plant-based diet as a single measure, while ignoring impacts, such as food waste and sociocultural aspects, given the complexity of the definition of a sustainable diet. Nonetheless, our index captures adherence to a plant-based diet, and can be used for this purpose as well.

Our study has some limitations. The questionnaire measures various dimensions of sustainable diets, yet does not quantify GHGEs, which is the main metric for evaluating environmental burden [52]. Nevertheless, our aim was to develop a tool for assessing individual preferences and not to assess the impact of nutrition on the environment, a field with extensive research. The generalizability of this study may be limited to younger, healthy and well-educated adults, and more studies will be needed to further tailor the questionnaire in elderly and in lower socioeconomic-status populations. However, the structure of the questionnaire enables adaptations to various populations in one or more dimensions. The SHED Index does not cover food security. Since we aimed to focus on dietary patterns and environmental behaviour of individuals, the index captures dietary choices but not economic constraints. Further development of the SHED Index might consider new indicators that would capture food security and diet biodiversity, and possibly even communal aspects of eating.

In summary, since sustainable healthy eating is a relatively new notion, a valid and reliable index is an essential tool for its evaluation. The SHED Index, which was presented and validated in this study, offers a short and practical tool for measuring both healthy dietary patterns and pro-sustainability behaviours. Moreover, it provides a tangible methodology that can be used in further research and intervention studies, as well as in daily practice. Changing dietary preferences for better health and reduced environmental burden is an emerging international goal. The integration of healthy and sustainable measures into one composite score is necessary for assessing the implementation of this goal.

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Availability of data and material (data transparency) The data will be available upon reasonable request.Code availability (software application or custom code) The syntax will be available upon reasonable request.

Declarations

Conflict of interest (include appropriate disclosures) The authors have no competing interests related to this work.

Ethics approval The study was approved by the ethics committee of Tel-Hai College.

Consent to participate (include appropriate statements) All the participants in the study signed an informed consent form.

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