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Assessing Sustainable and Healthy Diets in Large-Scale Surveys: Validity and Applicability of a Dietary Index Based on a Brief Food Group Propensity Questionnaire Representing the EAT-Lancet Planetary Health Diet

Agustin Miranda[1,*], Anna Maria Murante[2], Federica Manca[2], Fabio Consalez[2,3], Anant Jani[4], Fabrice DeClerck[5,6], Matthieu Maillot[7], Eric Verger[1]

[1] *MoISA, Univ Montpellier, CIHEAM-IAMM, CIRAD, INRAE, Institut Agro, IRD, Montpellier, France;* [2] *Sant'Anna School of Advanced Studies, Institute of Management, Pisa, Italy;* [3] *Sustainable Food Systems, ICLEI European Secretariat, Freiburg im Breisgau, Germany;* [4] *Heidelberg University, Heidelberg, Germany;* [5] *EAT Forum, Oslo, Norway;* [6] *Alliance of Bioversity & CIAT, CGIAR, Montpellier, France;* [7] *MS-Nutrition, Marseille, France*

ABSTRACT

Background: Ensuring healthy diets within planetary boundaries is essential. However, current instruments measuring adherence to the EAT-Lancet planetary health diet are unsuitable for large-scale surveys. Simplified tools assessing consumption frequency can improve response rates, lower costs, and facilitate administration.

Objectives: This study aimed to develop a practical and concise index for evaluating relative adherence to the EAT-Lancet diet across large-scale multicountry surveys.

Methods: First, the EAT-Lancet Consumption Frequency Index (ELFI) was developed using a brief food propensity questionnaire of 14 food groups representing the planetary health diet from the Food systems that support transitions to hEalthy And Sustainable dieTs survey, which encompassed 27 European countries ($n = 27{,}417$). Subsequently, ELFI was further validated using 24-h dietary recalls from the Third French Individual and National Food Consumption Survey ($n = 1645$), correlating it with the valid EAT-Lancet Index (ELI), which evaluates absolute adherence, as well as with food group consumption, measures of nutritional health (nutrient adequacy and diet quality), and environmental impact. Analyses included assessment of reliability, structural validity, concurrent validity, and nomological validity.

Results: ELFI showed strong reliability ($\alpha > 0.80$) and factor analysis revealed a 2-factor solution: "foods to encourage" and "foods to balance and to limit." Confirmatory factor analysis demonstrated that ELFI is structurally valid. Concurrent validity was confirmed as it was associated with sex, age, education, income, household size, physical activity, and smoking habit ($P < 0.05$). ELFI correlated with ELI (0.44, $P < 0.0001$) and food group consumptions. Regarding nomological validity, the ELFI subscores for "foods to encourage" and "foods to balance and to limit" were associated with better nutritional health ($\beta = 0.62$ and 0.23, respectively; $P < 0.0001$) and a lower environmental impact ($\beta = –0.16$ and –0.36, respectively; $P < 0.0001$).

Conclusions: ELFI approach represents a valuable and easy-to-implement index for evaluating relative adherence to sustainable and healthy diets in large-scale multicountry studies.

Keywords: sustainable diet, dietary index, healthy eating, dietary assessment, nutrition surveys, food behaviors

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Abbreviations: AIC, Akaike Information Criterion; ALA, alpha-linolenic acid; ANCOVA, analysis of variance; ANSES, French Agency for Food, Environmental and Occupational Health and Safety; AS, adequacy subscore; BIC, Bayesian Information Criterion; CD, coefficient of determination; CDAI, Composite Dietary Antioxidant Index; cDQI, Comprehensive Diet Quality Index; CFA, confirmatory factor analysis; CFI, Comparative Fit Index; CU, consumption unit; DII, Dietary Inflammatory Index; EFA, exploratory factor analysis; ELD-I, EAT-Lancet Diet Index; ELDS, EAT-Lancet Diet Score; ELFI, EAT-Lancet Consumption Frequency Index; ELI, EAT-Lancet dietary index; FEAST, Food systems that support transitions to hEalthy And Sustainable dieTs project; FFQ, food frequency questionnaires; FPQ, food propensity questionnaires; GDQS, Global Diet Quality Score; INCA3, French Third Individual and National Study on Food Consumption Survey; KMO, Kaiser-Meyer-Olkin; LA, linoleic acid; LCA, life cycle assessment; METs, metabolic equivalent of task; MS, moderation subscore; PANDiet, Probability of Adequate Nutrient intake Diet score; PHDI, Planetary Health Diet Index; RMSEA, root mean square error of approximation; SEM, structural equation modeling; SRMR, standardized root mean square residual.

* Corresponding author. *E-mail address:* agustin.miranda@ird.fr (A. Miranda).

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Introduction

The dual burden of health and environmental impacts linked to current food systems calls for urgent policy-driven shifts toward more sustainable and nutritious diets [1,2]. In this scenario, the EAT-Lancet Commission introduced the planetary health diet in 2019, which emphasizes vegetables, fruits, legumes, whole grains, nuts, and fish, although limiting red meat, tubers, saturated fats, and added sugars, with moderate consumption of eggs, poultry, and dairy [3]. Despite concerns regarding cultural application, nutritional adequacy, affordability in low-income contexts, and its emphasis on individual behavior over structural change, the planetary health diet continues to serve as a central reference for integrating nutrition and environmental goals [4]. Since its release, studies on adherence to these guidelines have grown, highlighting the potential influence of consumers—whose food choices are shaped by personal preferences and market forces—in driving changes in food systems [5].

To assess adherence to the EAT-Lancet diet, researchers have developed various indices using traditional dietary assessment methods, including dietary recalls, food frequency questionnaires (FFQ), and food diaries [6]. However, despite increasing validation efforts [7–10], these approaches can be impractical in large-scale research settings. First, traditional methods for quantifying food intake are technically complex and challenging to collect, process, and analyze [11,12]. Also, from a financial perspective, these methods require substantial investments to cover the costs of data collection, processing, and analysis [11,13]. This situation becomes even more complicated when applied to multicountry studies involving large populations, as the associated time and cost issues are amplified [14]. Additionally, from the respondents' perspective, the use of these techniques can lead to participant burden, especially in multidimensional surveys designed to address a wide range of topics [15]. Therefore, it is essential to develop more cost-effective and simpler methods for such studies. Food propensity questionnaires (FPQs), also known as nonquantitative FFQs, represent a valuable alternative that can reduce costs, simplify administration, and improve response rates [16]. FPQs are designed to evaluate food consumption patterns and preferences by collecting information on the frequency of consumption for specific food groups (for example, fruits) or items (for example, oranges), thereby facilitating the analysis of dietary habits and the factors influencing food choices without requiring precise quantitative measures [17]. FPQs are often tailored into brief formats to assess specific dietary components and have been validated against quantitative dietary assessment methods, making the FPQ approach particularly useful in large-scale studies [18]. Moreover, data derived from FPQs are useful for developing valid dietary indices [19–22].

Given the limitations of current EAT-Lancet indices for large-scale studies, the need for streamlined assessment tools is evident [23,24]. Dietary indices should reliably capture adherence to dietary guidelines and demonstrate validity through consistent correlations with relevant health and environmental outcomes [25]. Although no definitive reference standard currently exists for assessing adherence to the planetary health diet, the EAT-Lancet Index (ELI) serves as an appropriate validated comparator. In this sense, ELI was developed using data from a large Swedish cohort and offers a robust foundation for designing FPQ-based indices, as it is based in quantitative FFQ data, includes 14 food groups aligned with the planetary health diet (categorized as emphasized or restricted) and applies a simple 0–3 points scoring system that is easily replicable in large-scale surveys [26]. Moreover, emerging evidence supports the validity of the ELI, demonstrating its reliable metric properties and its association with improved health outcomes, nutrient adequacy, diet quality, and reduced environmental impacts, including lower greenhouse gas emissions and decreased water, air, and land pollution [6,10,27]. Building on this evidence, this study aimed to develop and validate the EAT-Lancet Consumption Frequency Index (ELFI), a brief and practical index based on FPQ to assess relative adherence to the planetary health diet in large-scale multicountry surveys.

Methods

Study design and participants

The study included 2 samples. The first used data from the Food systems that support transitions to hEalthy And Sustainable dieTs (FEAST) project, a large-scale multicountry survey involving 27,417 adults across 27 European countries [28]. FEAST employed a cross-sectional design with stratified sampling to recruit ≥1000 participants per country, ensuring representativity by age, gender, and education. Recruitment was conducted via a market-insights platform using demographic quotas. Participants completed an 88-item online survey covering dietary patterns, consumption behaviors, sustainability perceptions, policy views, and sociodemographic data. Ethical approval was granted by the joint Ethics Committee of Scuola Superiore Sant'Anna and Scuola Normale Superiore (Resolution No. 29/2023 and amendments). Further methodological details are available elsewhere [29].

For the second phase of validation, data were drawn from the Third French Individual and National Food Consumption Survey (INCA3) survey, a nationally representative cross-sectional study conducted from 2014 to 2015, including 4114 individuals [30]. For this study, adults who completed both 24-h recalls and FPQ were included. Mis-reporters (those who under- or over-report their food intake) were excluded based on the basal metabolic rate estimated using the Henry equation and the cutoff values suggested by Black et al. [31,32], resulting in a final sample of 1645 adults (690 men, 955 women). INCA3 followed the Declaration of Helsinki and was approved by the French Data Protection Authority (Decision DR 2013-228) and the Health Research Advisory Committee (Opinion 13.055). Verbal informed consent was obtained from all participants.

Index development and validation

Measuring the relative adherence to the planetary health diet in large-scale survey

To assess dietary behaviors across Europe, the FEAST survey developed a brief FPQ representing the EAT-Lancet planetary health diet [29]. This questionnaire evaluated the consumption of 14 key food groups outlined in the planetary health diet, including whole grains, tubers and starches, vegetables, fruits, dairy foods, red meats, poultry, eggs, fish and shellfish, legumes, unsaturated oils, animal fats and saturated oils, and added Q2 sugars [3]. Participants reported their consumption of these food groups using 7 frequency categories: never, once to 3 times per month, once per week, 2–3 times per week, 4–6 times per week, daily (once a day), and 2 or more times daily.

Subsequently, a quantile-based scoring system was used to assess relative adherence to the planetary health diet. This approach is particularly useful in the context of dietary indices involving multiple food groups, where specific cutoffs may not be established for each individual component. In such cases, population-based cutoffs allow each component to contribute meaningfully to the overall score by capturing intake variation across the population [33]. Accordingly, this approach categorizes participants based on the distribution of their consumption levels within the study population, typically dividing them into groups such as quartiles or tertiles [34]. By standardizing adherence scores relative to the population distribution, this method is especially valuable in large-scale surveys where precise individual-level intake data may be difficult to obtain. It provides a practical means of evaluating participants' alignment with dietary guidelines, although maintaining the index's ability to discriminate between levels of adherence.

The food groups covered in the FEAST survey, along with their specifications about food items and the complete scoring system, are shown in Figure 1. Whole grains, vegetables, fruits, fish and shellfish, legumes, nuts, and plant oils were classified as foods to encourage, whereas tubers, dairy foods, red meats, eggs, and poultry were categorized as foods to balance. In contrast, animal fats and added sugars were designated as foods to limit. This classification aligns with the criteria of EAT-Lancet; however, red meats and tubers were considered as foods to balance rather than foods to limit. Accordingly, other EAT-Lancet-based dietary indices have adopted these modifications in nutrient-rich food groups to account for micronutrient adequacy [5,35].

A detailed description of the scoring procedure is available in Supplemental Figure 1. Briefly, food groups to encourage were scored according to tertiles, with points ranging from 1 to 3 based on consumption frequency. Specifically, 1 point was assigned to the first tertile (low consumption frequency) and 3 points to the third tertile (high consumption frequency). Individuals reporting no consumption scored 0 points. In contrast, for foods to limit and to balance, the scoring system was inverted, meaning a higher score indicated lower consumption frequency. Furthermore, for tubers, dairy foods, red meats, poultry, and eggs, a nuanced and flexible scoring approach was employed, with cutoffs based on interdisciplinary expert consensus. This method considered minimum consumption levels whereas avoiding the imposition of absolute restrictions on nutrient-rich foods, also ensuring that adherence does not disproportionately favor specific dietary patterns, such as veganism or vegetarianism, over other balanced diets. The use of minimum intake levels is a common approach in the development of EAT-Lancet-based indices to ensure that adherence supports adequate nutrient intake, which is one of the main challenges of the planetary health diet [5,35]. The total ELFI score was calculated as the sum of its 14 food component scores, with a theoretical range of 0 to 42. A higher score indicates higher relative adherence to the planetary health diet.

Calculating ELFI in INCA3

The same approach and tertile-based scoring system in the FEAST study were replicated in INCA3 survey to assess index validity. INCA3 survey employed a FPQ featuring 75 food items selected based on 3 key criteria: their contribution to total

Food group	Food items	Approach used	Never	One to three times a month	Once per week	From 2 to 3 times a week	From 4 to 6 times a week	Daily (one time a day)	Daily (2 or more times a day)
Whole grains	Whole grains (rice, wheat, corn, bread and other whole grain products in the form of breakfast cereals, biscuits, tortillas and other sources) (Not including refined versions of these products, such as white rice and white bread) and pseudograins (amaranth, buckwheat, quinoa).	To encourage	0	1	1	2	2	3	3
Tubers	Tubers or starches (potatoes, cassava and their derivatives, such as potato flour and instant mashed potatoes).	To balance	3	3	3	2	1	0	0
Vegetables	Vegetables (all vegetables, excluding legumes and starchy vegetables).	To encourage	0	1	1	1	2	2	3
Fruits	Fruits (All fruits and berries, excluding fruit juices).	To encourage	0	1	1	1	2	2	3
Dairy foods	Dairy foods (milk, yogurt, cheese, from cow, goat or buffalo) (excluding butter and cream).	To balance	3	3	3	2	1	1	0
Red meats	Beef, lamb, goat, pork, and red meat in its processed form (e.g., sausages, ham, bologna, dried meat, etc.).	To balance	3	3	2	2	1	0	0
Poultry	Chicken and other poultry (e.g., duck, geese, turkey).	To balance	3	3	3	2	1	0	0
Eggs	Eggs (from chicken and other poultry).	To balance	3	3	3	2	1	0	0
Fish	Fish and shellfish (e.g., mussels, shrimp, octopus).	To encourage	0	1	2	3	3	3	3
Legumes	Legumes (e.g., dried or canned beans, lentils, chickpeas, peas, soy, tofu, soy products).	To encourage	0	1	2	2	3	3	3
Nuts	Nuts (e.g., pistachios, walnuts, hazelnuts, almonds, peanuts, nut mixes) (excluding sweetened and salted nuts).	To encourage	0	1	2	2	3	3	3
Oils	All plant oils (e.g., olive oil, sunflower oil, soybean oil, etc.) and plant margarines.	To encourage	0	1	1	1	2	3	3
Fats	Animal fats and other saturated fats (butter, tallow, lard, coconut oil, cream).	To limit	3	2	2	1	1	0	0
Added sugars	Added sugars (all sugars – white, brown, honey, agave syrup, maple syrup), sweets/desserts, fruit-juices and sugar-sweetened beverages (e.g., soda).	To limit	3	2	2	1	1	0	0

FIGURE 1. Scoring system used in the EAT-Lancet Consumption Frequency Index (ELFI) for assessing relative adherence to the Planetary Health Diet in the FEAST large-scale multicountry survey. Food groups are categorized by intended consumption: green indicates foods to encourage, which are nutritious and have a relatively low environmental impact; yellow represents foods to balance, which can support health when consumed in moderation but have a high environmental impact; red highlights foods to limit, due to low nutritional value and high environmental burden. FEAST, Food systems that support transitions to hEalthy And Sustainable dieTs project.

nutrient and chemical intake, their impact on interindividual variability in total intake, and a significant increase in consumer rates observed in the 3-day food record compared with the 7-d record from the previous INCA2 survey [30,35]. Participants reported their consumption status for each food item with a yes/no response and indicated their frequency of consumption over the past 12 mo. To standardize food intake frequency, the reported number of days per month was transformed into 7 categorical frequency scales from "never" to "every day." The complete list of foods included in the FPQ is available elsewhere [35].

Assessing the validity of the ELFI against 24-h recall

Data derived from the 24-h recalls of the INCA3 survey were used to calculate the ELI, a validated measure based on consumption quantity to assess absolute adherence to the planetary health diet that serves as a benchmark for testing ELFI validity [26]. Dietary intake was assessed using 3 nonconsecutive 24-h dietary recalls, which included 2 weekdays and 1 weekend day over a 3-wk period [30]. Participants were contacted by phone to report all foods and beverages consumed during the previous day, utilizing validated photographs of standard portion sizes in France. The energy and nutrient content of the foods were derived from the 2016 database of the French Centre d'Information sur la Qualité des Aliments [37]. Recipes containing various ingredients were disaggregated into their components as described in previous work [10]. In this study, the dietary data were used to calculate adherence indices for the EAT-Lancet diet, along with nutritional quality and environmental scores for each individual participating in the INCA3 survey.

The ELI comprises 14 food groups divided into 2 categories: 7 positive groups, referred to as "emphasized foods" (vegetables, fruits, unsaturated oils, legumes, nuts, whole grains, and fish), and 7 negative groups, known as "limited foods" (beef and lamb, pork, poultry, eggs, dairy, tubers, and added sugar) [26]. The alignment of dietary intake, measured in grams per day (g/d, without adjustments for daily energy), with EAT-Lancet recommendations is evaluated using a scoring system based on a graded scale that ranges from 0 (indicating non-compliance) to 3 points (indicating high compliance). Total scores for the ELI can range from 0 to 42 points. Further details regarding ELI are available elsewhere [26].

Assessing nutritional health and environmental indicators

Since the planetary health diet aims to be both healthy and sustainable, it is essential to assess whether the index aligns with nutritional and environmental indicators. Nutritional health was evaluated across: *1*) nutrient adequacy, defined as the extent to which the diet meets physiological requirements without deficiencies or excesses [38]; *2*) diet quality, reflecting the balance and diversity of healthy compared with unhealthy foods [39,40]; and *3*) the inflammatory/antioxidant profile, which captures the diet's role in modulating chronic disease risk [41–43].

The Probability of Adequate Nutrient intake Diet (PANDiet) score assessed nutrient adequacy by estimating the probability of meeting dietary reference intakes for 33 nutrients [38]. It includes adequacy (27 nutrients) and moderation (6 nutrients) subscores, each scaled 0–100, with higher total scores reflecting better adequacy. Diet quality was further evaluated using the Global Diet Quality Score (GDQS) and the comprehensive Diet Quality Index (cDQI) [39,40]. The GDQS comprises 25 food groups: 16 healthy, 7 unhealthy, and 2 that are unhealthy when consumed in excessive amounts. Scores range from 0 to 49, with subscores GDQS+ and GDQS− reflecting healthy and unhealthy food intake, respectively. The cDQI distinguishes between healthy and unhealthy plant- and animal-based foods across 17 components (pDQI and aDQI), with a total score ranging from 0 to 85.

The Dietary Inflammatory Index (DII) assessed the diet's inflammatory potential based on 34 food parameters and biomarker-derived weights [41,42]. Additionally, the Composite Dietary Antioxidant Index (CDAI) [43,44] was used to capture exposure to dietary antioxidants (vitamins A, C, E, selenium, manganese, and zinc). Higher DII indicates greater inflammatory potential, whereas higher CDAI reflects increased antioxidant capacity. The calculation procedures for both indices are described in detail elsewhere [10].

Environmental impact was assessed using the Agribalyse 3.1.1 database [45], which applies life cycle assessment to food products. Indicators included greenhouse gas emissions, land and water use, particulate matter emissions, eutrophication, ecotoxicity, resource use, and aggregated product environmental footprint. Methodological details about nutritional and environmental indicators are available elsewhere [10,46].

Sociodemographic variables included sex, age, education, household size, and income per consumption unit [30]. BMI was calculated from self-reported height and weight and categorized according to WHO criteria [47]. Physical activity and sedentary behavior were evaluated using the Recent Physical Activity Questionnaire [30,48], which provided estimates of weekly metabolic equivalent of task values, total sedentary hours, and categorized participants into 4 groups: inactive/sedentary, inactive/non-sedentary, active/sedentary, and active/non-sedentary [49].

Statistical analysis

Analyses were conducted in Stata 18 (StataCorp) using a significance level of $P < 0.05$ and applying INCA3 survey weights. Means and SDs were calculated for continuous variables, and percentages for categorical variables. The index's metric properties (structural, convergent, concurrent criterion, and nomological validity) were evaluated following established dietary index validation frameworks [10,23–25].

Structural validity, which evaluates whether index components reflect the intended dimensions [23], was tested using Cronbach's alpha (α), exploratory factor analysis (EFA), and confirmatory factor analysis (CFA) in the FEAST sample. A value of $\alpha > 0.70$ was considered acceptable for internal consistency. EFA, conducted on half the sample ($n = 13{,}709$), used varimax-rotated principal component analysis; factors were retained based on eigenvalues >1.0, scree plot inspection, and loadings ≥0.30, and data adequacy was confirmed according to Kaiser-Meyer-Olkin (KMO) and Bartlett's tests. CFA on the remaining half ($n = 13{,}708$) employed maximum-likelihood structural equation modeling (SEM), with model goodness-of-fit evaluated using standard statistical indices. In addition, a bifactor model tested whether the index could be considered one overall construct [50].

Convergent validity, which examines correlations with similar constructs [10,25], was assessed by comparing ELFI (based on FPQ data) with ELI (from 24-h recalls) using Pearson's r for total scores and Spearman's ρ for food groups. Regression models, controlling for age and sex, were employed to examine ELFI's independence from total energy intake (kcal/d, excluding alcohol). Participants were categorized into ELFI quintiles (Q1–Q5), and differences in food intake (g/d) across groups were analyzed using analysis of variance and Jonckheere–Terpstra trend tests.

Concurrent-criterion validity was assessed using multiple regression to examine whether ELFI varies across sociodemographic groups with known dietary differences [51]. Results are reported as adjusted β coefficients and 95% confidence intervals.

Nomological validity, assessing whether ELFI fits within a broader theoretical network [52], was tested via SEM involving 4 latent constructs: "foods to encourage," "foods to balance and to limit," "nutritional health" (PANDiet, GDQS, cDQI, DII, CDAI), and "environmental impact" (greenhouse gas emissions, particulate matter, terrestrial eutrophication, water and land use). The selected indicators reflect 5 core dimensions of nutritional health: nutrient adequacy (assessing the likelihood of meeting micronutrient requirements), dietary quality and balance (evaluating the consumption of healthy compared with unhealthy foods), inflammatory potential (linking diet to pro- or anti-inflammatory effects), and antioxidant capacity (capturing intake of key antioxidant nutrients). Together, these indicators support a comprehensive assessment of nutritional health across multiple physiological pathways and are closely linked to chronic disease risk. On the other hand, the 5 environmental indicators were chosen for their ability to capture key pressures on air, land, and water systems, and because maintaining an equal number of measured variables for each latent outcome variable enhances model parsimony, identification, and interpretability. The nomological model was estimated using maximum-likelihood with Satorra-Bentler correction [53]. Standardized path coefficients (β) were reported, which indicate the strength and direction of associations, allowing comparison across pathways. This facilitates evaluation of each latent predictor's influence and supports the model's theoretical validity. Spearman's correlations between ELFI and individual nutritional/environmental indicators were also calculated and visualized in radar plots.

Results

The mean ELFI score in the FEAST sample was 23.71 (3.60). Tubers and poultry had the highest average scores [2.29 (1.01) Q4 and 2.04 (0.99)], whereas added sugars and fats had the lowest [1.19 (0.90) and 1.30 (0.88)]. Reliability analysis showed item-total correlations ranging from 0.44 to 0.65, and item-rest correlations from 0.33 to 0.55 (Table 1). The overall ELFI had strong internal consistency ($\alpha = 0.83$), being also acceptable at subscale level. No increase in α was observed after removing food groups, indicating good internal homogeneity.

As for structural validity, EFA was supported by a KMO of 0.87 and a significant Bartlett's test [$\chi^2(45) = 968.85$, $P < 0.001$]. The EFA revealed a 2-factor solution (based on eigenvalues, a scree plot, and information criteria), with all items exhibiting factor loadings above 0.30 (Supplemental Figure 2). After retaining the 2 factors, the model explained 41% of the total variance. The first factor, labeled "foods to encourage," showed high loadings for fruits, vegetables, legumes, nuts, whole grains, fish and shellfish, and oils, accounting for 21% of the variance. The second factor, "foods to balance and to limit," comprised red meats, fats, poultry, eggs, added sugars, tubers, and dairy foods, explaining 20% of the variance. Additionally, CFA confirmed a bidimensional structure, with all 3 models demonstrating acceptable fit (Supplemental Table 1).

The mean ELFI score in the INCA3 sample was 19.62 (3.35). Regarding food groups, poultry and vegetables received the highest scores [2.60 (0.58) and 2.29 (0.83), respectively], whereas dairy foods and added sugars scored the lowest [0.36 (0.81) and 0.67 (0.90), respectively]. The ELFI total score showed a positive correlation with ELI ($r = 0.44$, $P < 0.0001$), and there was also a positive correlation between the equivalent food groups ($\rho = 0.11$–0.49, $P < 0.0001$) (Table 2). Normal distribution was confirmed for both total scores (Supplemental

TABLE 1

Reliability analysis of the EAT-Lancet Consumption Frequency Index (ELFI) in the FEAST survey ($n = 27{,}417$).

Item (food group)	M	SD	Min	Max	Item-total correlation	Item-rest correlation	α
Whole grains	1.75	0.91	0	3	0.54	0.43	0.82
Vegetables	1.67	0.66	0	3	0.57	0.50	0.82
Fruits	1.69	0.70	0	3	0.53	0.45	0.82
Fish	1.75	1.01	0	3	0.55	0.43	0.82
Legumes	1.68	0.83	0	3	0.57	0.48	0.82
Nuts	1.70	0.91	0	3	0.57	0.47	0.82
Oils	1.79	0.92	0	3	0.55	0.45	0.82
Fats	1.30	0.88	0	3	0.52	0.42	0.82
Added sugars	1.19	0.90	0	3	0.44	0.33	0.83
Tubers	2.04	1.01	0	3	0.64	0.54	0.81
Dairy foods	1.42	0.91	0	3	0.50	0.40	0.82
Red meats	1.70	0.91	0	3	0.57	0.47	0.82
Poultry	2.04	0.99	0	3	0.64	0.54	0.81
Eggs	1.98	1.02	0	3	0.65	0.55	0.81
Total ELFI	23.71	3.60	6	40			0.83
Foods to encourage	12.03	3.74	0	21			0.74
Foods to balance and to limit	11.68	4.17	0	21			0.75

Abbreviations: FEAST, Food systems that support transitions to hEalthy And Sustainable dieTs; M, mean; α, Cronbach's alpha coefficients calculated after the removal of individual food groups.

TABLE 2

Descriptive statistics of the EAT-Lancet Consumption Frequency Index (ELFI) and its correlation with EAT-Lancet Index (ELI) and the habitual food consumption (g/d) from 24-h recall in the INCA3 survey ($n = 1645$).

	M	SD	Min	Max	ELI[1]		Consumption (g/d)	
					Correlation	*P*	Correlation	*P*
ELFI[2]	19.62	3.35	8	32	0.44	<0.0001	–	–
Whole grains	1.73	0.93	0	3	0.21	<0.0001	0.26	<0.0001
Vegetables	2.29	0.83	0	3	0.33	<0.0001	0.33	<0.0001
Fruits	2.07	0.90	0	3	0.49	<0.0001	0.49	<0.0001
Fish and shellfish	1.86	0.87	0	3	0.26	<0.0001	0.28	<0.0001
Legumes	1.33	0.80	0	3	0.14	<0.0001	0.15	<0.0001
Nuts	1.35	0.83	0	3	0.23	<0.0001	0.28	<0.0001
Added sugars	0.67	0.90	0	3	0.19	<0.0001	–0.22	<0.0001
Tubers	2.01	1.04	0	3	0.16	<0.0001	–0.17	<0.0001
Dairy foods	0.36	0.81	0	3	0.29	<0.0001	–0.38	<0.0001
Red meats	1.27	0.92	0	3	0.27	<0.0001	–0.22	<0.0001
Poultry	2.60	0.58	0	3	0.11	<0.0001	–0.15	<0.0001
Eggs	2.12	1.05	0	3	0.18	<0.0001	–0.19	<0.0001

Abbreviations: INCA3, French Third Individual and National Study on Food Consumption Survey; M, mean.

[1] ELI was calculated using 24-h recall data.

[2] ELFI was calculated based on food frequency data.

Figure 3). Additionally, the correlations between ELFI food groups and the absolute food consumption were as expected: positive correlations for food groups to encourage ($\rho = 0.15–0.49$, $P < 0.0001$), whereas negative correlations for food groups to balance or to limit ($\rho = –0.15$ to $–0.38$, $P < 0.0001$). The correlation between ELFI total and energy was negligible (–0.09) (Supplemental Figure 4).

Table 3 presents a comparison of food consumption across ELFI quintiles. Significant positive trends were observed for all food groups categorized as “to encourage,” with the most notable differences in fruits, vegetables, and nuts. In contrast, significant negative trends were identified for “foods to balance and to limit,” particularly concerning added sugars and red meats. No difference in poultry consumption was observed.

Figure 2 [47] presents the results of the concurrent-criterion validity analysis. ELFI scores were significantly higher among women ($\beta = 0.09$, $P < 0.0001$), adults aged 45–64 and 65–79 compared with those aged 18–44 ($\beta = 0.21$ and 0.19, both $P < 0.0001$), and individuals with higher education levels ($\beta = 0.16$, $P < 0.0001$). A marginally higher score was observed for those with high school to 2 y of higher education ($\beta = 0.06$, $P = 0.057$). Higher income was positively associated with ELFI, with significant differences observed when comparing against €900/mo ($\beta = 0.10–0.16$, all $P \leq 0.042$). Individuals living alone scored higher than those in households of 3 ($\beta = –0.08$, $P = 0.010$) or >5 members ($\beta = –0.12$, $P < 0.0001$). Sedentary individuals, regardless of activity level, had lower scores ($\beta = –0.15$, $P = 0.001$; $\beta = –0.13$, $P = 0.005$), as well as smokers ($\beta = –0.06$, $P = 0.019$). ELFI scores tended to be higher in individuals with normal weight, though this was not statistically significant.

When analyzing the bivariate correlations of the ELFI with nutritional and environmental indicators (Figure 3), ELFI positively correlated with the adequacy of 16 nutrients, including fatty acids, fiber, vitamins (thiamine, folate, vitamins C, D, and E), minerals (magnesium, copper, and manganese), carbohydrates, saturated fatty acids, and sugars. In contrast, 3 nutrients

TABLE 3

Food consumption (g/d) across EAT-Lancet Consumption Frequency Index (ELFI) quintiles in INCA3 survey ($n = 1645$).

Food groups	Q1 ($n = 364$)		Q5 ($n = 385$)		ANOVA		Trend[1]	
	M	SD	M	SD	F[2]	*P*	Direction	*P* trend
Whole grains	11.46	23.69	23.30	40.89	11.54	<0.0001	+	<0.0001
Vegetables	199.20	176.52	312.46	199.53	19.49	<0.0001	+	<0.0001
Fruits	116.84	128.90	248.56	169.88	50.03	<0.0001	+	<0.0001
Fish and shellfish	25.99	38.91	41.72	45.19	7.71	<0.0001	+	<0.0001
Legumes	12.88	36.58	8.34	20.50	4.25	0.0020	+	0.0017
Nuts	2.88	7.02	7.04	13.50	12.81	<0.0001	+	<0.0001
Oils	7.31	9.41	10.04	10.62	4.21	0.0022	+	<0.0001
Fats	32.33	23.19	23.62	17.89	9.67	<0.0001	–	<0.0001
Added sugars	62.68	45.22	41.43	38.08	15.86	<0.0001	–	<0.0001
Tubers	73.09	85.93	53.10	63.62	4.45	0.0014	–	<0.0001
Dairy foods	236.69	185.96	202.96	147.48	2.08	0.0812	–	0.0026
Red meats	108.64	71.73	77.39	58.97	11.05	<0.0001	–	<0.0001
Poultry	30.66	37.55	30.71	36.56	2.03	0.0884	±	0.6938
Eggs	28.11	29.06	25.56	27.81	3.51	0.0073	–	0.0004

Abbreviations: ANOVA, analysis of variance; INCA3, French Third Individual and National Study on Food Consumption Survey; M, mean.

[1] Jonckheere–Terpstra test for trend.

[2] F-statistic testing for overall differences between group means.

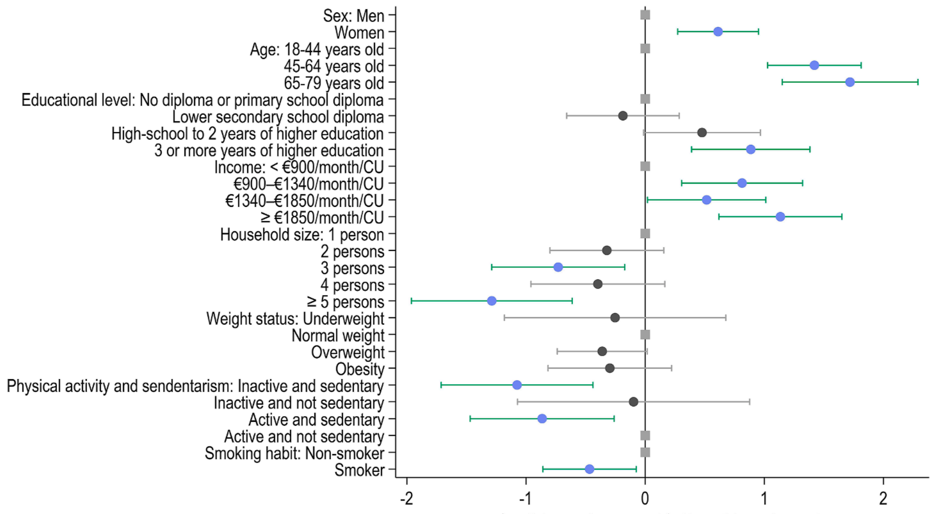

FIGURE 2. Multivariate regression coefficient plot and confidence intervals illustrating the association of EAT-Lancet Consumption Frequency Index (ELFI) with sociodemographic variables in INCA3 survey ($n = 1645$). CU refers to consumption unit. Weight status was classified according to WHO BMI categories. CU, consumption unit; INCA3, French Third Individual and National Study on Food Consumption Survey.

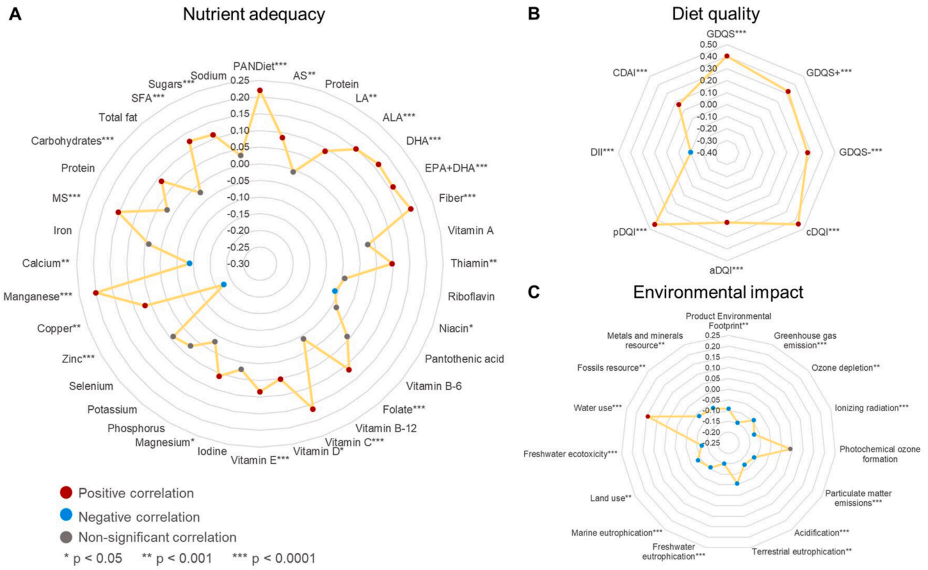

FIGURE 3. EAT-Lancet Consumption Frequency Index (ELFI) correlations with nutrient adequacy (A), diet quality (B), and environmental impact (C) in INCA3 survey ($n = 1645$). Values expressed as Spearman's correlation coefficients. ALA, alpha-linolenic acid; AS, adequacy subscore; CDAI, Composite Dietary Antioxidant Index; DII, Dietary Inflammatory Index; DQI, Comprehensive Diet Quality Index (comprehensive, animal, or plant); GDQS, Global Diet Quality Score; INCA3, French Third Individual and National Study on Food Consumption Survey; sLA, linoleic acid; MS, moderation subscore; PANDiet, Probability of Adequate Nutrient intake Diet score.

showed negative correlations with ELFI: zinc, calcium, and niacin. Regarding diet quality, ELFI exhibited positive correlations with all indicators, except for the DII, which had a negative correlation, indicating that ELFI is related with lower diet inflammatory potential. ELFI was associated with a reduced environmental impact, showing negative correlations with most environmental indicators, except for water use, which had a positive correlation, and photochemical ozone formation, which was not significant.

Figure 4 shows the nomological validity results. The model demonstrated a good fit and was able to explain 90% of data variability. All measured variables showed significant loadings on their respective latent variables ($P < 0.0001$). Regarding the structural model (that is, the relationships between the latent variables), expected associations were found. Specifically, "foods to encourage" factor was positively associated with "nutritional health" ($\beta = 0.62$, $P < 0.0001$) and negatively associated with "environmental impact" ($\beta = -0.16$, $P < 0.0001$). Similarly, "foods to balance and to limit" factor was positively correlated with "nutritional health" ($\beta = 0.23$, $P < 0.0001$) and negatively correlated with "environmental impact" ($\beta = -0.36$, $P < 0.0001$). Additionally, there was a negative

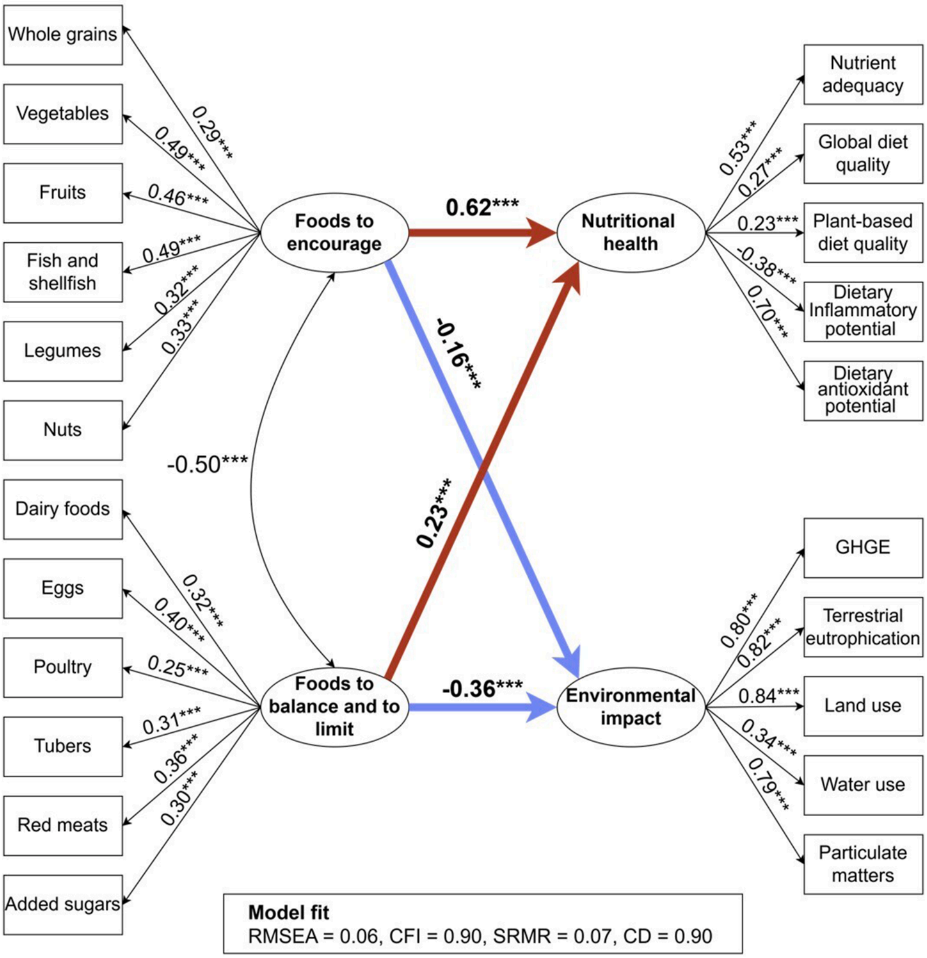

FIGURE 4. Assessment of nomological validity of the EAT-Lancet Consumption Frequency Index (ELFI): structural equation model with standardized coefficients in INCA3 survey ($n = 1645$). The rectangles represent observed variables, whereas the ellipses represent latent variables. The straight black arrows from latent variables to observed variables represent factor loadings. Colored arrows between latent variables denote standardized regression coefficients, with red arrows indicating positive associations and blue arrows indicating negative associations. Double-headed arrows between latent variables indicate correlations. The use of 3 asterisks denotes a P value < 0.0001. For the sake of clarity, errors are not shown. CD, coefficient of determination; CFI, comparative fit index; INCA3, French Third Individual and National Study on Food Consumption Survey; RMSEA, root mean square error of approximation; SRMR, standardized root mean square residual.

correlation between the “foods to encourage” and “foods to balance and to limit” ($\beta = -0.50$, $P < 0.0001$).

Discussion

This study aimed to develop and validate the ELFI, a brief and practical index based on FPQ for assessing relative adherence to the planetary health diet in large-scale multicountry surveys. Findings support its reliability and validity for this purpose. ELFI has strong internal consistency, a robust multidimensional structure, and correlations with ELI, 24-h recall data, nutritional health, and environmental impact indicators. These results underscore ELFI’s applicability for evaluating sustainable and healthy diets in population studies.

The mean ELFI score in both samples was notably lower than the maximum possible scores, indicating that few individuals closely follow the EAT-Lancet planetary health diet. This finding is consistent with other indices measuring adherence to the planetary health diet. For instance, the ELI index had an average score of 18 (out of 42) [26], the World Index for Sustainability and Health averaged 46 (out of 130) [54], and the Planetary Health Diet Index (PHDI) had a mean of 60 (out of 150) [8]. Moreover, the food group scores in this study align with dietary trends in Europe and France, supporting the validity of ELFI [55, 56].

Regarding reliability and structural validity, ELFI demonstrated strong internal consistency with a Cronbach’s α exceeding 0.80, indicating that its food groups represent a unified construct. Each food group contributed uniquely to the index, with no redundancy or gain in reliability upon removal [23]. ELFI demonstrated internal consistency comparable with other validated indices of healthy and sustainable diets [57,58]. ELFI surpasses EAT-Lancet-based indices, which have reported α

values around 0.50 [8,59,60]. Although a minimum α of 0.70 is generally recommended, nutritional metrics often require more flexible thresholds (above 0.50) due to the complexity and multidimensionality of dietary constructs [8].

ELFI is structurally valid with a bidimensional structure, where “foods to encourage” and “foods to balance and to limit” provide distinct, independent information, supporting both the total score and subscores that reflect dietary behaviors influencing health and environmental impact. Multidimensionality is also present in other indices based on the planetary health diet, such as the PHDI [8,60]. The bidimensional structure is similar to other indices such as the Healthful Eating Indicator, which includes subscores for “recommended” and “discretionary” foods [61], and the GDQS, with GDQS+ for healthy foods and GDQS- for unhealthy foods [39]. Importantly, recent evidence links GDQS+ and GDQS- scores to improved health outcomes, including reduced risks of noncommunicable diseases [62–64], underscoring the value of separating dietary components. Thus, future studies should further explore associations between ELFI and health outcomes.

Convergent validity of the ELFI was supported by its moderate positive correlation with ELI, a valid measure aligned in structure and methodology, and associated with positive health outcomes and lower dietary costs [10,26,27,65–67]. The moderate agreement between ELFI and ELI is expected, as both assess adherence to the same dietary pattern; however, methodological differences may introduce variability. In this sense, ELFI focuses on consumption frequency, whereas ELI considers intake quantity, which can lead to some differences [68]. Nevertheless, the correlation of 0.44 indicates a moderate association between the indices, suggesting that frequency and quantity represent complementary dimensions of dietary adherence [69]. Moreover, ELFI food group scores were directionally consistent with corresponding ELI values and 24-h recall data (g/d), supporting its validity in capturing the target dietary pattern. For example, higher ELFI scores for fruits and vegetables aligned with higher reported intakes in recalls, reinforcing its utility as a proxy for habitual dietary behavior. From a research perspective, ELFI may be more suitable for population-based research, where consumption frequency is a key indicator and a rapid and efficient assessment is required, whereas ELI is better suited for detailed analyses where precise intake quantification is critical.

Furthermore, ELFI was independent of energy intake, consistent with other EAT-Lancet indices [5,8,10]. A positive correlation with energy intake could bias scores toward high-calorie diets regardless of nutritional quality or sustainability [23], whereas a strong negative correlation might reflect very low-calorie diets that risk nutrient inadequacy. Such associations could misrepresent diet quality by favoring diets that are either excessive or insufficient in calories rather than truly balanced and sustainable [23].

ELFI varied across sociodemographic groups, supporting its concurrent-criterion validity and aligning with findings from the same context [10]. For instance, higher scores among women and university graduates have also been reported for the French Nutrition and Health Program-Guideline Score and the Sustainable Diet Index [70,71]. Likewise, most EAT-Lancet indices demonstrate associations with sex, age, education, income, physical activity, and smoking status [10,26,66,72–78]. Although normal weight was marginally linked to higher ELFI, this association was not statistically significant, potentially due to bias in self-reported BMI [79].

A key strength of this study is the demonstration of nomological validity through significant associations of both “foods to encourage” and “foods to balance and to limit” subscores with nutritional health and environmental impact. Higher scores on “foods to encourage” were strongly associated with better nutritional health, although also showing a modest inverse relationship with environmental impact. Conversely, higher scores on “foods to balance and to limit” were linked to reduced environmental impact but also positively associated, albeit weaker, with nutritional health. This pattern reflects the planetary health diet’s design: foods “to encourage” (such as fruits, vegetables, legumes, and nuts) are nutrient-dense and improve dietary quality [80], whereas “to balance and to limit” foods (such as red meats and dairy) have greater environmental costs [81,82], though they may still contribute some nutrients.

Overall, ELFI was associated with lower environmental impacts, except for water use. These results align with previous evidence demonstrating the environmental benefits of the planetary health diet [10]. Notably, it has been reported up to a 50% reduction in greenhouse gas emissions among individuals with the highest adherence [83]. Reductions in other environmental indicators have been reported and may be attributed to increased intake of plant-based foods and reduced consumption of animal-based foods and tubers [84,85]. However, this may pose nutritional challenges, as animal-based foods are important sources of nutrients such as iron, zinc, and vitamin B_{12}, consistent with our findings [10,86]. Similar to other EAT-Lancet-based indices, ELFI was associated with increased water use, warranting particular attention in regions facing water stress [10,84].

Our findings should be considered alongside certain limitations. Although INCA3 may not capture recent dietary trends, it remains the latest representative dataset for France. Its FPQ omitted oils and fats, limiting full validation, though these food groups were included in the FEAST survey. The cross-sectional design of both datasets limits causal inference. Nevertheless, the large, multicountry sample strengthens the reliability and generalizability of ELFI. Limitations of the Agribalyse v.3.1.1 must be also acknowledged, including its lack of data on soil carbon storage, biodiversity, organic food distinctions, and incomplete water use and waste data [87,88].

Inherent limitations of FPQs and the scoring system also apply. As self-reported instruments, FPQs are subject to measurement errors related to recall bias, long-term intake estimation, restricted food lists, social desirability bias (overreporting healthy and underreporting unhealthy foods), and literacy requirements. Also, reported frequencies may not reliably capture habitual intake, introducing potential bias [18]. Furthermore, the quantile-based scoring system, whereas practical for large-scale assessments, relies on population-specific cutoffs that limit generalizability [89]. Additionally, categorizing individuals into quantiles may mask more detailed variations in diet and assume homogeneity within each group, potentially overlooking individual differences. Nevertheless, this approach offers a feasible and consistent way of evaluating dietary alignment when absolute intake data are unavailable. Notably, relative adherence (that is, ELFI) correlated absolute scores (that is, ELI), indicating that both indices reflect similar dietary behaviors and supporting the applicability of ELFI in large-scale studies. Moreover, although ELFI was developed using European data, its quantile-based scoring system ensures its adaptability across populations. By relying on relative intake distributions rather than fixed thresholds, ELFI can be recalibrated using local data to reflect country- or region-specific consumption patterns. This flexibility enhances its potential global applicability. However, future studies are needed to validate ELFI in non-European populations, particularly in low- and middle-income countries.

Like other EAT-Lancet indices, ELFI tends to disproportionately favor plant-based diets, which could increase the risk of specific nutrient shortfalls [86]. To mitigate this, we applied flexible scoring to "foods to balance." ELFI demonstrated weak inverse associations with zinc, calcium, and niacin (coefficients <0.20). Although modest, these results align with concerns about the EAT-Lancet diet's one-size-fits-all approach [10,90], which may inadequately address iron, calcium, and zinc requirements across diverse populations [86]. Future research should refine this framework to improve nutrient adequacy without compromising environmental and health goals, a challenge anticipated in the next EAT-Lancet update [91].

In conclusion, ELFI is a valid, reliable, and easy-to-implement tool that enables the assessment of relative adherence to the planetary health diet in large-scale multicountry surveys, offering a practical and scalable tool for evaluating dietary patterns across diverse populations.

Q10 Uncited refrences

[36]

Author contributions

The authors' responsibilities were as follows – AM, EV: conceptualized and designed the study, drafted the manuscript, and primary responsibility for the final content; AM: conducted the statistical analyses; FC, FM, AMM: coordinated the FEAST questionnaire design, led the survey implementation and critically reviewed the manuscript draft; AJ: supervised the project and contributed a critical review of the draft; FD, MM: contributed in the methodology for index development and validation; and all authors: read and approved the final manuscript.

Conflict of interest

The authors report no conflicts of interest.

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Data availability

Data from the Third French Individual and National Food Consumption Survey (INCA3) are available on the data.gouv.fr platform at: https://www.data.gouv.fr/fr/datasets/donnees-de-consommations-et-habitudes-alimentaires-de-letude-inca-3/. Data on the environmental impacts of foods consumed in France are available on the agribalyse.ademe.fr platform. FEAST anonymous survey data will be made available coherently with the FEAST Data management Plan: https://feast2030.eu/sites/default/files/feast/resources_files/2024/FEAST_WP1_DMP-PlanDel1.2_D_20240528_V2.pdf.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tjnut.2025.06.018.

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