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Original Research

Adherence to the EAT-Lancet diet and its association with micronutrient intake in the urban population of eight Latin American countries

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ABSTRACT

The EAT-Lancet Commission proposed a dietary framework aimed at reducing the ecological footprint of diets worldwide, but research on adherence to this diet in Latin America is limited. This study aimed to describe the adherence of urban diets in 8 Latin American countries to the EAT-Lancet diet and its association with micronutrient intake inadequacy. This cross-sectional study analyzed baseline data from the Latin American Study of Nutrition and Health, involving 6835 participants from Argentina, Brazil, Chile, Colombia, Costa Rica, Ecuador, Peru, and Venezuela. Data collection included two 24-hour recalls, alongside

Abbreviations: BMI, body mass index; DGV, dark green vegetables; EAR, Estimated Average Requirement; ELANS, Estudio Latino Americano de Nutrición y Salud / Latin American Study of Nutrition and Health; g, grams; GLM, generalized linear regression model; mg, milligram; µg, micrograms; NAR, Nutrient Adequacy Ratio; PAL, physical activity level; PHDI, Planetary Health Diet Index; ReV, red and orange vegetables; SD, standard deviation; SES, socioeconomic status; TEI, total energy intake.

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socio-demographic variables. Usual dietary intake was estimated via the Multiple Source Method and micronutrient inadequacy was evaluated with the Nutrient Adequacy Ratio. The Planetary Health Diet Index (PHDI; ranged between 0 and 150) assessed adherence to the EAT-Lancet diet. Adherence was low (29.7%) across the region, with an average PHDI score of 44.6 ± 9.2 points. Costa Rica had the highest adherence (32.9%), while Argentina had the lowest (25.8%). Older participants, those with overweight/obesity, and with higher socioeconomic status, education, and physical activity had higher adherence. Higher adherence was associated with increased inadequacy risks for cobalamin, vitamin D, and calcium, but decreased risks for pyridoxine, folate, vitamin C, magnesium, and zinc. The study suggests that low adherence may stem from a disconnect between culturally ingrained dietary habits and the EAT-Lancet recommendations, which are primarily informed by nutritional epidemiology and environmental considerations. Recognizing and honoring diverse food cultures is crucial for promoting dietary practices that support human health and environmental sustainability.

1. Introduction

Global food systems significantly contribute to harmful effects on the environment [1,2] and the development of noncommunicable diseases related to poor diet globally [3,4]. Therefore, over recent decades, there has been increasing recognition of the importance of a radical transformation of food systems to ensure that nutritious, safe, affordable, and sustainable diets are available to all [4–7]. This transformation represents a crucial pathway to decreasing mortality rates associated with the food system [3], as well as reducing greenhouse gas emissions, and water and land use [1,8,9].

To promote a model of production and consumption of healthier food with lower environmental impact, the EAT-Lancet Commission on "Healthy Diets from Sustainable Food Systems" proposed in 2019 a dietary pattern that seeks human and environmental health simultaneously under the principle of "One Health" [1,10,11]. This pattern is known as the "Planetary Health Diet" and proposes the first scientific targets for consuming a healthy diet within the environmental limits of food production [1,10]. Overall, this dietary pattern involves (1) high consumption of vegetables, fruits, whole grains, legumes, nuts, seeds, and unsaturated vegetable oils; (2) low to moderate consumption of dairy, seafood, chicken, and eggs; and (3) low to minimal consumption of red meat, processed meat, added sugar, refined grains, and starchy vegetables [1].

The dietary pattern proposed by EAT-Lancet has been compared with other healthy eating guidelines and patterns from different regions of the world [12–15]. These comparisons have shown that, depending on the country and culture, compliance with the EAT-Lancet reference diet may require significant changes to an individual's eating habits. Furthermore, the nutritional quality of the diet is not always guaranteed in different contexts [16].

Studies employing diverse methodologies and designs have used different indices to measure relative adherence to the EAT-Lancet diet, typically expressed by quintiles (Q) of the index. When compared to participants with low adherence to the reference diet (Q1), several studies have found favorable outcomes in those participants with high adherence (Q5) to the EAT-Lancet diet, including lower risks of type 2 diabetes [17,18], cardiovascular disease morbidity and mortality [18–21], overweight/obesity [22,23], and cancer [24]. Additionally, high adherence has been associated with better global cognitive functioning and slower cognitive decline among cognitively healthy older adults [25], among others benefits.

Regarding nutrient intake, dietary reference intakes (DRIs) vary across world regions [26–31]. However, on the American continent, DRIs issued by the US Institute of Medicine are generally accepted as reference standards for assessing nutrient intakes. Among DRIs, the Estimated Average Requirement (EAR) is the primary reference used to assess the adequacy of estimated nutrient intakes in groups, with participants having usual intakes below their corresponding EAR generally considered to have inadequate intakes [26]. Some studies [16,32], though not all [33,34], have reported a lower risk of inadequate intake of iron, fiber, potassium, folate, and vitamin C among participants with higher adherence to the reference diet (Q5 vs Q1) [16,32]. Given that the EAT-Lancet diet promotes the consumption of pulses, dark green leafy vegetables, and red and orange fruits and vegetables (typically rich in vitamin A), it has been shown that estimated intakes of folate and vitamin A are generally adequate for adults and women of reproductive age [16]. However, estimated intakes of cobalamin, calcium, iron, and zinc may be inadequate [33], likely due to the diet's limited consumption of dairy and meat products, which are rich sources of these nutrients [33]. Inadequate intakes of iron and zinc are also common in populations consuming high amounts of phytates and few animal-sourced foods [27,34].

Limited research has been conducted to assess adherence to the EAT-Lancet diet in Latin America, and a first step is evaluating adherence to the standard pattern, helping to understand how regional food culture align with it. Most investigations in this area have focused on Brazil, using the Planetary Health Diet Index (PHDI) [11,35–37], and Mexico, employing the Healthy and Sustainable Dietary Index (HSDI) [38]. Despite the use of different indices and methodologies to evaluate adherence, findings from both studies suggest a low level of adherence to the EAT-Lancet dietary pattern in populations of both countries.

Latin America faces a complex epidemiological landscape, marked by the dual challenge of communicable and noncommunicable diseases [39]. This situation is further compounded by the region's susceptibility to the impacts of global warming, which places additional pressure on health systems and threatens the sustainability of food production. To address these concerns, it is important to explore strategies that could enhance resilience and promote sustainable food systems in the region. One approach that has gained attention is studying adherence to the EAT-Lancet dietary pattern. Research on this diet may provide valuable insights for improving public health outcomes and reducing environmental degradation linked to food production, contributing to long-term sustainability in Latin America. Nonetheless, it has been noted that such diet may not necessarily ensure adequate intake of certain nutrients, such as iron, calcium, and zinc, which are essential for the nutritional needs of individuals [33].

This study aimed to describe the adherence of urban populations in eight Latin American countries to the EAT-Lancet reference dietary pattern and to explore the association between this adherence and micronutrient intake. It offers a new perspective on the topic in the Latin American region, utilizing data from the Latin American Study of Nutrition and Health (Estudio Latino Americano de Nutrición y Salud, ELANS). This study is particularly relevant to urban areas, as at least 80% of the region's population resides in urban settings [40].

2. Methods and Materials

2.1. Sample and setting

This cross-sectional study used the baseline data from the ELANS, whose design and sampling are described in detail elsewhere [40–42]. The ELANS is an urban representative household-based multinational study conducted from September 2014 to August 2015; involving 9218 participants from eight Latin American countries: Argentina, Brazil, Chile, Colombia, Costa Rica, Ecuador, Peru, and Venezuela. The ELANS was designed to assess anthropometric measures, nutritional intakes, and physical activity levels. It used a random complex multistage sample, stratified by geographical region, sex, age, and socioeconomic status [42]. Misreported energy intake (EI) was previously calculated for the ELANS study by Previdelli et al. [43], following the methodology used by McCrory et al. [44]. After excluding cases of misreported EI from the overall ELANS sample, the final plausible sample of this study comprised 6835 men and women, including adolescents (aged 15-18 years) and adults aged 19 to 65 years. Differences between included and excluded samples were found in 3 countries (Argentina, Peru, and Venezuela), and physical activity levels low and high ($p < .05$) (Table S1).

The ELANS protocol received approval from the Western Institutional Review Board (20140605) and was registered on clinicaltrials.gov (NCT02226627). Additionally, it was approved by the local ethics committees in each respective country. Before participating in the survey, all participants provided their informed consent/assent. Moreover, this study protocol was approved on June 21st, 2023, by the Scientific and Ethics Committee of the Costa Rican Institute for Research and Education on Nutrition and Health (INCIENSA) (IC-2023-02).

2.2. Data collection

2.2.1. Demographic and socioeconomic status variables

A questionnaire was used to collect data on sex, age, and years of education. A standardized 3-level system was established to classify educational levels: basic for non-formal and complete/incomplete primary school; medium for complete/incomplete secondary school; and high for university studies or superior [45]. The socioeconomic status (SES) was evaluated through a questionnaire utilizing a format specific to each country, designed to adhere to national legislative standards or recognized local layouts. It was classified as low, middle, and high status, based on the national indices of each country [40,45].

2.2.2. Anthropometric assessment

Height and weight measurements, conducted by trained nutritionists adhering to standardized protocols [46], were used to calculate the body mass index (BMI). For participants under 18 years old, the BMI was categorized based on z-score cut-off criteria for age and sex as recommended by the World Health Organization (WHO) [47]. For individuals aged 18 years and older, BMI was categorized as follows: underweight, BMI <18.5 kg/m^2; normal weight, BMI 18.5 to 24.9 kg/m^2; overweight, BMI 25.0 to 29.9 kg/m^2; and obese, BMI ≥ 30.0 kg/m^2 [48].

2.2.3. Physical activity level assessment

The International Physical Activity Questionnaire (IPAQ) was used to assess participants' physical activity level (PAL) [40]. IPAQ data helped estimate each participant's total energy expenditure (TEE) from physical activities. TEE was calculated using age, height, weight, and overall activity level, based on a predictive equation from the Institute of Medicine; and was also required for the EI misreporters identification [42,49]. PAL was determined by summing PAL values from individual activities. Walking, moderate, and vigorous physical activities (measured in min/week) were evaluated using IPAQ's standardized methods to classify PAL as low, moderate, or high [42,50].

2.2.4. Dietary assessment

The ELANS dietary assessment included 2 household visits, with an interval of ≤ 8 days between visits. Trained interviewers conducted a 24-hour dietary recall (24HR) during each visit to record all food and beverage consumption from the prior day, including both weekdays and weekends with a proportional distribution across the sample, ensuring representation of day-to-day intake variations. Trained nutritionists supervised the recalls and converted the recorded measures into grams and milliliters [42].

All locally sourced and traditional foods documented across both 24HR were standardized using a USDA composition table to ensure nutritional equivalency. Mandatory food fortification regulations in each respective country were also considered [42,45]. Energy and nutrient values were derived using the Nutrition Data System for Research (NDS-R) software version 2013 [51].

2.2.4.1. *Usual dietary intake* Using intake data from both 24HR for each participant, the Multiple Source Method (MSM) (http://mss.dife.de/tps/en) [52,53] was applied to estimate the usual intake of the 16 components of the Planetary Health Diet Index (PHDI), as well as energy and various nutrients for the plausible ELANS sample, including: carbohydrates, added sugars, dietary fiber, protein, total fat, monounsaturated fat, polyunsaturated fat, saturated fat, trans fat, cholesterol, nine vitamins (thiamin [vitamin B1], riboflavin [vitamin B2], niacin [vitamin B3], pyridoxine [vitamin B6], folate equivalents [vitamin B9], cobalamin [vitamin B12], vitamin C, vitamin A, and vitamin D), and five minerals (calcium, iron, magnesium, zinc, and sodium). Furthermore, usual nutrient intakes were energy-adjusted using the nutrient residual model proposed by Willett et al. [54]. This adjustment aimed to mitigate bias in estimating nutrient intake due to its significant association with energy intake.

2.2.4.2. *Nutrient adequacy* The Nutrient Adequacy Ratio (NAR) was calculated for 13 micronutrients by comparing each participant's usual intake to the Estimated Average Requirement (EAR) for their respective sex and age group, in accordance with guidelines from the National Academy of Medicine of the United States [26]. The EAR values are used as they are appropriate for assessing nutrient intakes within groups and for planning nutritionally adequate diets for populations. Consequently, the following Eq. (1) was applied [55,56]:

$$NAR = \left(\frac{Usual\ dietary\ intake_{nutrient}}{EAR_{nutrient}} \right) \quad (1)$$

Nutrient adequacy for a specific nutrient was determined as follows: adequate intake was defined as an NAR value ≥1, and inadequate intake as an NAR value <1.

2.3. Planetary Health Diet Index assessment

The Planetary Health Diet Index (PHDI) was used to assess adherence to the EAT-Lancet dietary pattern. This diet index includes all EAT-Lancet food groups and uses a gradual scoring system, evaluating components based on consumption quantity [11,36]. Scores in the PHDI are derived from an energy intake ratio, calculated by dividing the energy from all foods within a PHDI component by the total energy intake from all foods consumed each day (except alcoholic beverages, given their exclusion in the reference diet) [1,11]. For each participant, the energy intake from each PHDI component across both days was used to estimate the usual energy intake of that component using the MSM. The usual intake of each PHDI component was then used to calculate the corresponding PHDI score.

The PHDI includes 16 components into 4 categories: *adequacy* (nuts and peanuts, fruits, legumes, vegetables, whole grain cereals), *optimum* (eggs, dairy products, fish and seafood, tubers and potatoes, vegetable oils), *ratio* (dark green vegetables/total vegetables, red-orange vegetables/total vegetables), and *moderation* (red meat, poultry, animal fats, added sugars). Adequacy, optimum, and moderation categories score from 0 to 10 points, while components in the ratio category score from 0 to 5 [11]. Details regarding the PHDI components, scoring criteria, and cutoff points according to the EAT-Lancet diet are shown in Table 1.

To illustrate the relative contribution of each component, we used the following criteria to classify them: high relative contribution, ≥50% of available points by component; intermediate relative contribution, 20% to 49% of available points by component; low relative contribution, <20% of available points by component. These cutoff points were established by the authors to simplify comparisons of the relative contributions of PHDI components. Total PHDI score ranges from 0 to 150, with higher scores indicating greater adherence to the EAT-Lancet diet [11,57], and adherence to the reference diet can be estimated from the PHDI score divided by the total possible PHDI points [37]. Detailed information on PHDI development, validity, and reliability can be found elsewhere [11].

All foods consumed by the ELANS plausible sample were initially disaggregated to their ingredient level, before classifying the ingredients into the 16 PHDI components, following the methodology outlined by Cacau et al. [11] for extracting PHDI components from food consumption data. Furthermore, ultra-processed foods underwent careful disaggregation to estimate their content of added sugar, vegetable oils, and animal (saturated) fat using the USDA composition table. This ensures that each of these components was accurately placed within the corresponding categories of the PHDI, thus avoiding under or overestimation. This process underwent review by 4 trained nutritionists.

2.4. Statistical analyses

Continuous variables were presented as means ± standard deviations (SD) with 95% confidence intervals (95% CI), while categorical variables were expressed as frequencies (%). The Shapiro-Wilk test was employed to assess the normal distribution of continuous variables. Comparisons of PHDI scores among groups based on sex, age group, country, SES, educational level, PAL, and weight status were conducted using the Mann-Whitney test or Kruskal-Wallis test, followed by the Bonferroni procedure for multiple-comparison correction.

Generalized linear regression models (GLM) with gamma distribution and Log link function were utilized to evaluate the association between relative adherence to the PHDI and usual energy and nutrient intakes. The gamma distribution with the Log link function was preferred since energy and nutrient intakes can only take positive values [58]. Furthermore, multivariate Poisson regression models with robust variance were employed to examine the association between relative adherence to the PHDI and intake inadequacy of protein and 13 micronutrients with EAR. This choice was made over logistic regression to avoid the usual overestimation of the risk product of the logistic regression's odds ratio, particularly in cross-sectional studies and high-prevalence events (≥10%) [59–62].

GLM and Poisson models were adjusted for sex, age, SES, and country. The association trend was evaluated using orthogonal polynomial contrast for linear trend among PHDI quintiles within each model. Non-multicollinearity within each model was assessed using the variance inflation factor. Additionally, over-dispersion was evaluated in the Poisson models.

Table 1 – Planetary Health Diet Index components and food groups, cutoff points for scoring, and corresponding point values.

Components / Food groups	Score (points) [a]				
	0	5	10	5	0
Adequacy component	Energy density (%TEI)				
Nuts and peanuts	0.0	⟷	≥11.6		
Legumes [b]	0.0	⟷	≥11.3		
Fruits	0.0	⟷	≥5.0		
Vegetables	0.0	⟷	≥3.1		
Whole grains	0.0	⟷	≥32.4		
Optimum component					
Eggs	0.0	⟷	0.8	⟷	≥1.5
Fish and seafood	0.0	⟷	1.6	⟷	≥5.7
Tubers and potatoes	0.0	⟷	1.6	⟷	≥3.1
Dairy [c]	0.0	⟷	6.1	⟷	≥12.2
Vegetables oils [d]	0.0	⟷	16.5	⟷	≥30.7
Ratio component					
DGV/total vegetables [e]	0.0	⟷ 29.5		29.5 ⟷	100.0
ReV/total vegetables [f]	0.0	⟷ 38.5		38.5 ⟷	100.0
Moderation component					
Red meat [g]	≥2.4	⟷	0.0		
Chicken and substitutes	≥5.0	⟷	0.0		
Animal fats [h]	≥1.4	⟷	0.0		
Added sugars	≥4.8	⟷	0.0		

[a] All table values are expressed as energy densities of the EAT-Lancet dietary pattern (%TEI). [b] Includes soy. [c] Excludes dairy fats. [d] Includes palm oil. [e] Ratio of energy intake from dark green leafy vegetables to total vegetables. [f] Ratio of energy intake from red and orange vegetables to total vegetables. [g] Includes beef, lamb, and pork. [h] Includes lard, tallow, and dairy fats. Adapted from Cacau *et al.*, 2021 [11].

%TEI: percentage of total energy intake; DGV: dark green leafy vegetables; ReV: red and orange vegetables.

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[e] Ratio of energy intake from dark green leafy vegetables to total vegetables.
[f] Ratio of energy intake from red and orange vegetables to total vegetables.
[g] Includes beef, lamb, and pork.
[h] Includes lard, tallow, and dairy fats. Adapted from Cacau et al. [11].

All tests were conducted with a 2-tailed approach, and p-values $< .05$ were considered statistically significant. Data analysis was performed using Stata software version 14.1 (2015, College Station, TX, USA) [63] and IBM SPSS® (version 27, IBM Corp) [64].

3. Results

3.1. *General characteristics and Planetary Health Diet Index (PHDI) score of the study participants*

The average age of the sample was 36.0 ± 14.1 year (data not shown). The majority of the study sample was 51.8% female, 83.0% aged 19 to 59 year, 52.2% with low SES, 60.6% with a basic education level, 58.9% with low PAL, and 60.0% of the participants had overweight/obesity (Table 2).

The average PHDI score of the sample was 44.6 ± 9.2 points (out of 150), and the distribution of the PHDI can be found in the *Supplementary materials* (Fig. S1). The PHDI score was significantly higher in the 19 to 59 year and the 60 to 65 year age groups compared to the adolescents' group (44.7 ± 9.2 and 45.6 ± 9.4 vs 43.7 ± 9.4 points, respectively, $p = .006$). There were significant differences in PHDI scores among countries ($p < .001$). Costa Rica had the highest score (49.3 ± 9.0), followed by Brazil (47.6 ± 9.1), Ecuador (46.5 ± 8.2), and Venezuela (45.1 ± 8.6). Chile (44.0 ± 8.8) and Peru (43.9 ± 8.4) had similar scores ($p > .05$) and both ranked fifth place. Colombia came sixth (42.0 ± 8.6), while Argentina had the lowest score (38.7 ± 8.6) (Table 2, Fig. S2).

Regarding SES and educational level, participants with high SES (45.9 ± 8.9 points) and with medium (45.2 ± 9.2 points) and high (45.3 ± 9.0 points) educational levels had significantly slightly higher PHDI scores ($p < .001$), compared to participants with middle (44.9 ± 9.6 points) and low (44.2 ± 9.0 points) SES and with basic education (44.3 ± 9.3 points) (Table 2). Participants with high PAL had significantly higher PHDI scores than participants with low or moderate PAL (45.4 ± 9.8 vs 44.4 ± 9.1 and 44.45 ± 9.1 points, respectively; $p = .037$). Also, participants with overweight/obesity showed a significantly higher PHDI score than those without excess weight (44.9 ± 9.1 vs 44.2 ± 9.4 points, respectively; $p = .005$). There were no significant differences in the PHDI between men and women ($p = .558$) (Table 2).

Table 2 – Planetary Health Diet Index among subgroups of participants in the Latin American Study of Nutrition and Health (2016) (n = 6835).

Characteristic	Total		PHDI score			
	n	%	Mean	SD	95% CI	*p*-value[a]
Overall	6835	100.0	44.6	9.2	44.4-44.8	-
Sex						
Men	3294	48.2	44.7	9.5	44.4-45.0	.558
Women	3541	51.8	44.6	9.0	44.3-44.9	
Age group						
15-18 y	698	10.2	43.7[a]	9.4	43.0-44.4	.006
19-59 y	5675	83.0	44.7[b]	9.2	44.4-44.9	
60-65 y	462	6.8	45.6[b]	9.4	44.7-43.4	
Country						
Argentina	896	13.1	38.7[a]	8.6	38.2-39.3	<.001
Brazil	1471	21.5	47.6[b]	9.1	47.1-48.1	
Chile	629	9.2	44.0[c]	8.8	43.3-44.7	
Colombia	901	13.2	42.0[d]	8.6	41.4-42.5	
Costa Rica	570	8.3	49.3[e]	9.0	48.6-50.1	
Ecuador	582	8.5	46.5[f]	8.2	45.9-47.2	
Peru	890	13.0	43.9[c]	8.4	43.4-44.5	
Venezuela	896	13.1	45.1[g]	8.6	44.6-45.7	
Socioeconomic status						
Low	3565	52.2	44.2[a]	9.0	43.9-44.5	<.001
Middle	2597	38.0	44.9[b]	9.6	44.5-45.2	
High	673	9.8	45.9[c]	8.9	45.2-46.6	
Educational level						
Basic	4145	60.6	44.3[a]	9.3	44.0-44.5	<.001
Medium	2041	29.9	45.2[b]	9.2	44.8-45.6	
High	649	9.5	45.3[b]	9.0	44.6-45.9	
Physical activity level						
Not reported	152	2.2	45.4	10.2	43.7-47.0	-
Low	4024	58.9	44.5[a]	9.1	44.2-44.8	.037
Moderate	1832	26.8	44.5[a]	9.1	44.1-44.9	
High	827	12.1	45.4[b]	9.8	44.7-46.1	
Weight status[b]						
Non-overweight/obese	2731	40.0	44.2	9.4	43.9-44.6	.005
Overweight/obese	4104	60.0	44.9	9.1	44.6-45.2	

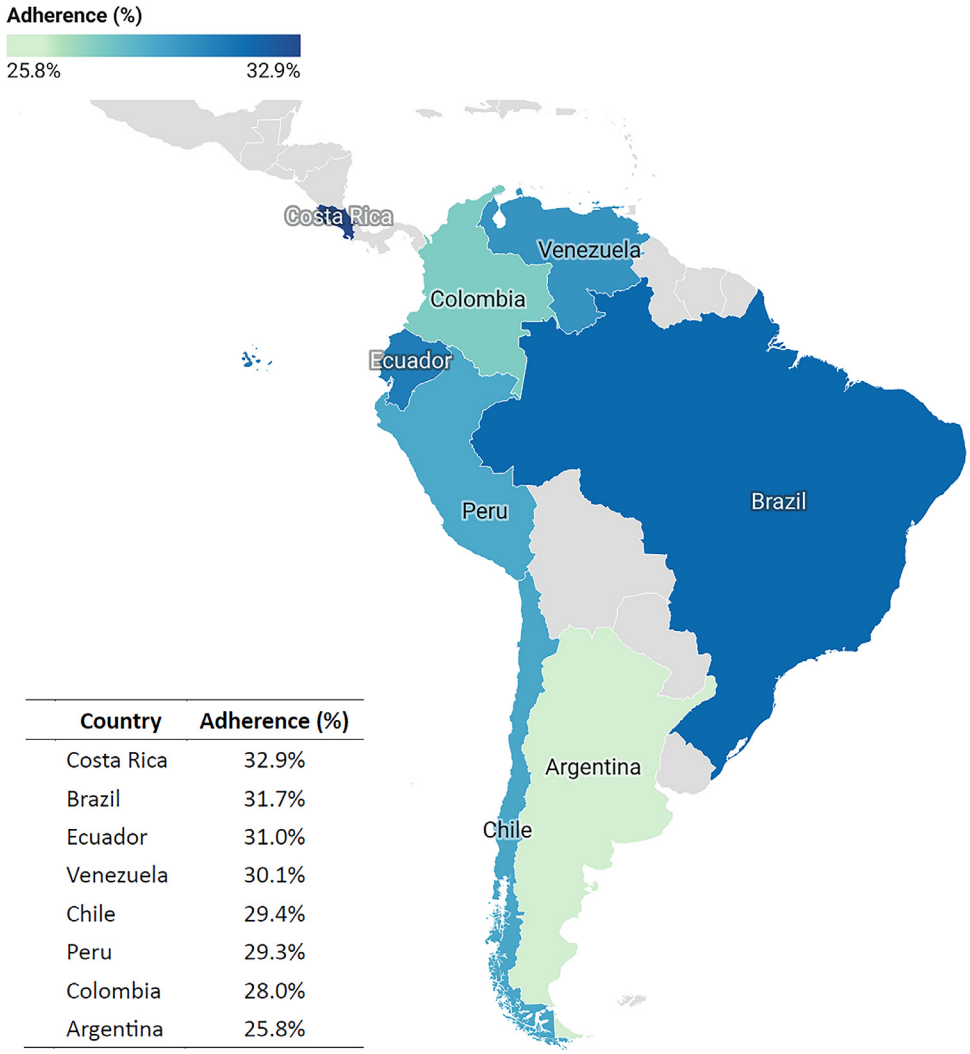
PHDI: Planetary Health Diet Index; SD: standard deviation; y: years.
[a] *p*-value corresponds to the Mann-Whitney or Kruskal-Wallis tests comparing groups. Labeled mean values within the same variable and without a common letter differ ($p < .05$).
[b] Weight status according to BMI categories.

The average adherence to the EAT-Lancet dietary pattern in the urban population of the 8 Latin American countries was 29.7%, and the adherence by country ranged from 32.9% in Costa Rica to 25.8% in Argentina (Fig. 1).

3.2. *Planetary Health Diet Index (PHDI) components score*

The overall descriptive analysis of the PHDI components score showed the average contribution of each component to the EAT-Lancet dietary pattern adherence (Table 3). While there were components with high relative contribution (≥50% of available points by component) to the adherence, as ReV/total ratio (74.6%), fruits (72.0%), vegetable oils (64.0%), and vegetables (57.8%); other components showed low relative contribution (<20% of available points by component) to the adherence, as nuts and peanuts (3.1%), whole cereals (3.4%), and DGV/total ratio (9.6%), among others. Most PHDI components had an intermediate relative contribution (20%-49% of available points by component) to adherence (Table 3).

Additional details regarding the descriptive analysis of the average PHDI component scores by country are available in the *Supplementary materials* (Table S2). All 16 PHDI components showed significant score differences among countries, with some components exhibiting higher variability. For instance, in the adequacy components Costa Rica had the highest score for legumes (4.76 ± 2.84), while Argentina had the lowest (0.78 ± 0.80). All countries scored less than 80% of available points for fruits and vegetables. Chile and Colombia had the highest fruit scores (7.91 ± 2.76 and 7.73 ± 2.86, respectively), while Argentina had the lowest (6.14 ± 3.12). For vegetables, scores ranged from 7.52 ± 2.20 in Ecuador to 4.62 ± 2.50 in Brazil. Regarding the moderation components, all countries showed low scores for red meat, chicken and substitutes, animal fats, and added sugars; indicating that typical consumption of these food groups highly



Country	Adherence (%)
Costa Rica	32.9%
Brazil	31.7%
Ecuador	31.0%
Venezuela	30.1%
Chile	29.4%
Peru	29.3%
Colombia	28.0%
Argentina	25.8%

Fig. 1 – Adherence[1] to the EAT-Lancet dietary pattern in the urban population of eight Latin American countries. Latin American Study of Nutrition and Health (ELANS, 2016) (n = 6835). [1]Adherence is expressed by the percentage of maximum achievable in the Planetary Health Diet Index score. Map created with ©2024 Datawrapper.

exceeds the EAT-Lancet dietary pattern recommendations (Table S2).

3.3. *Association between adherence to the Planetary Health Diet Index (PHDI) and usual energy/nutrient intakes*

Overall, after adjusting for sex, age, SES, and country, the high adherence to the PHDI (5th PHDI quintile) showed a positive and significant association with the intake of carbohydrates, dietary fiber, polyunsaturated fat, thiamin, pyridoxine, folate equivalents, vitamin C, vitamin A, iron, magnesium, and zinc (p-trend < .05) (Table 4). On the other hand, it had a negative and significant association with protein, total fat, saturated fat, trans fat, cholesterol, riboflavin, niacin, cobalamin, vitamin D, and calcium intakes (p-trend < .05). There were no significant associations between the high adherence to the PHDI and the intake of energy, added sugars, monounsaturated fat, and sodium intakes (p-trend > .05) (Table 4). Additional graphs, illustrating the association between the high adherence to the PHDI and the intake of energy and some nutrients, are shown in the *Supplementary materials* (Figs. S3 and S4).

Regarding nutrient inadequacy, after adjusting for sex, age, SES, and country, individuals in the 5th PHDI quintile (with high adherence to the EAT-Lancet dietary pattern) had 80.0%, 1.0%, and 11.9% significantly higher risks of nutrient inadequacy of cobalamin, vitamin D, and calcium, respectively (p-trend < .05); compared to those participants in the 1st PHDI quintile (with low adherence). At the same time, individuals in the 5th PHDI quintile also had 31.3%, 62.2%, 52.3%, 11.8%, and 18.2% significantly lower risks of nutrient inadequacy of pyridoxine, folate equivalents, vitamin C, magnesium, and zinc, respectively (p-trend < .05); compared to those participants in the 1st PHDI quintile. There was no significant association between the high relative adherence to the PHDI and the nutrient inadequacy of protein, thiamin, riboflavin, niacin, vitamin A, and iron (Table 5).

Table 3 – Descriptive analysis of the Planetary Health Diet Index components score among participants in the Latin American Study of Nutrition and Health (2016) (n = 6835).

PHDI components	Maximum points	Score		Relative contribution by component (%)
		Mean	SD	
Adequacy components				
Nuts and peanuts	10	0.3	1.0	3.1
Legumes	10	2.4	2.3	23.9
Fruits	10	7.2	3.0	72.0
Vegetables	10	5.8	2.6	57.8
Whole cereals	10	0.3	0.7	3.4
Optimum components				
Eggs	10	2.3	3.4	22.8
Fish and seafood	10	3.7	2.1	36.7
Tubers and potatoes	10	3.0	3.6	30.2
Dairy	10	4.9	3.1	48.8
Vegetable oils	10	6.4	1.7	64.0
Ratio components				
DGV / Total ratio[a]	5	0.5	0.8	9.6
ReV / Total ratio[b]	5	3.7	1.0	74.6
Moderation components				
Red meat	10	0.0	0.2	0.2
Chicken and substitutes	10	2.1	2.5	21.1
Animal fats	10	1.8	2.7	18.2
Added sugars	10	0.2	1.0	1.9
Total score	0-150	44.6	9.2	29.7

PHDI: Planetary Health Diet Index; SD: standard deviation; DGV: dark green leafy vegetables; ReV: red and orange vegetables.
[a] Dark green vegetables/total vegetables multiplied by 100.
[b] Red and orange vegetables/total vegetables multiplied by 100.

4. Discussion

This study aimed to assess the adherence of urban populations in eight Latin American countries to the EAT-Lancet dietary pattern and to explore the association between this adherence and micronutrient intake. As a result, we observed a low average adherence to the EAT-Lancet reference pattern in urban areas of Latin America, which aligns with the evidence found globally [16,17,19,37,38,65–67], despite the variation in tools used to determine adherence in most studies.

In our study, higher adherence to the EAT-Lancet diet, indicated by higher PHDI scores, was observed among older individuals, those with higher education, better socioeconomic status, greater physical activity, and those with overweight or obesity. These findings are similar to those of the first study that assessed adherence to the EAT-Lancet dietary pattern in 3 major Brazilian regions, except in that study, participants without overweight or obesity showed higher adherence to the reference diet [11,35]. Possible explanations for the higher adherence to the EAT-Lancet diet observed in participants with overweight or obesity may require further analyses since current findings on this topic are controversial [35,37,38,65,68–70]. To clarify this issue, future studies should consider the study design, relative adherence, and the prevalence of excess weight in the sample.

The low adherence to the EAT-Lancet dietary pattern in the urban population of the Latin American region could be associated with economic limitations. Analyses indicate that the daily cost of this diet surpasses the income of at least 1.58 billion people globally, rendering it unaffordable [10,71–73]. In Latin America, urban poverty is increasingly prevalent in developing countries, exceeding 50%. This phenomenon is more pronounced in urban areas due to accelerated urbanization and rural-to-urban migration [74], potentially limiting access to certain food groups essential for higher adherence to the EAT-Lancet pattern.

The low adherence to the EAT-Lancet reference diet in Latin America is likely due to the region's food culture differing from this dietary pattern. Even countries with relatively higher adherence, such as Costa Rica, Brazil, Ecuador, and Venezuela, still fall short in many food groups like nuts and seeds, legumes, fruits, vegetables, and whole grains [75]. In contrast, there is excessive consumption of red meat [75], saturated fats from animal sources [76], and added sugars [77], which negatively impact both health and the environment.

The gap between real-world dietary practices and the EAT-Lancet reference diet is evident when examining both adequacy and moderation components of the PHDI. While prioritizing foods with proven health benefits is important for formulating dietary patterns [10], global recommendations that focus solely on nutritional epidemiology can conflict with diverse food cultures at national and regional levels. This clash complicates the adoption of global patterns, as significant adjustments are required [78]. Thus, it is essential to adopt a broader perspective that incorporates food culture alongside nutrition from a more anthropological perspective, recognizing its key role in human development [79].

Future adaptations of the EAT-Lancet diet or any other alternative to improve diet quality and sustainability should in-

Table 4 – Association between high adherence to the Planetary Health Diet Index and usual energy/nutrient intakes among participants in the Latin American Study of Nutrition and Health (2016) (n = 6835).

Nutrient	β[a]	95% CI	p-value[b]	p-trend[c]
Energy (kcal)	-0.016	-0.032-0.000	.054	.087
Macronutrients				
Carbohydrates (g)	0.031	0.021-0.041	<.001	<.001
Added sugars (%TEI)	-0.001	-0.003 to 0.000	.124	.177
Dietary fiber (g)	0.250	0.227-0.272	<.001	<.001
Protein (g)	-0.028	-0.040 to -0.016	<.001	<.001
Total fat (g)	-0.020	-0.033 to -0.008	.002	.011
Saturated fat (g)	-0.099	-0.116 to -0.082	<.001	<.001
Monounsaturated fat (g)	-0.008	-0.023 to 0.007	.304	.689
Polyunsaturated fat (g)	0.069	0.052-0.087	<.001	<.001
Trans fat (g)	-0.032	-0.061 to -0.004	.026	.008
Cholesterol (mg)	-0.203	-0.225 to -0.181	<.001	<.001
Micronutrients				
Vitamins				
Thiamin (mg)	0.053	0.040-0.066	<.001	<.001
Riboflavin (mg)	-0.063	-0.080 to -0.047	<.001	<.001
Niacin (mg)	-0.013	-0.027 to -0.001	.041	.039
Pyridoxine (mg)	0.043	0.027-0.060	<.001	<.001
Folate equivalents (µg)	0.110	0.094-0.126	<.001	<.001
Cobalamin (µg)	-0.036	-0.068 to -0.005	.025	.010
Vitamin C (mg)	0.431	0.373-0.489	<.001	<.001
Vitamin A (µg)	0.048	0.009-0.087	.015	.036
Vitamin D (µg)	-0.221	-0.262 to -0.179	<.001	<.001
Minerals				
Calcium (mg)	-0.109	-0.136 to -0.083	<.001	<.001
Iron (mg)	0.078	0.063-0.093	<.001	<.001
Magnesium (mg)	0.125	0.112-0.138	<.001	<.001
Zinc (mg)	0.055	0.014-0.095	.009	.027
Sodium (mg)	0.015	-0.005 to 0.036	.144	.106

PHDI: Planetary Health Diet Index; %TEI: percentage of total energy intake.
Generalized linear regression model:
[a] Coefficient of energy/nutrient intake for the 5th PHDI quintile vs the 1st PHDI quintile (baseline); adjusted for sex, age, socioeconomic status, and country (gamma distribution with Log link function).
[b] p-value corresponds to the Wald test for the 5th PHDI quintile as a category of the PHDI within each model.
[c] p-value for trend corresponds to the linear trend among PHDI quintiles within each model.PHDI quintiles: min–max score/1st: 13.4-36.7; 2nd: 36.8-42.0; 3rd: 42.1-46.8; 4th: 46.9-52.3; 5th: 52.4-82.8. Usual nutrient intakes were energy-adjusted by the nutrient residual model.

corporate food groups that ensure sufficient intake of key nutrients of public health concern. The study's findings suggest that higher adherence to the EAT-Lancet diet is linked to an increased risk of inadequate intake of cobalamin, vitamin D, and calcium (nutrients typically found in animal-based foods). This is crucial given the high prevalence of inadequate calcium (85.7%) and vitamin D (98.2%) intake in ELANS countries [45].

A United Nations report highlights concerns that the restrictive nature of the EAT-Lancet dietary pattern regarding several food groups could lead to nutritional deficiencies and harm long-term human health, particularly for populations with higher nutritional needs [10,80]. Alexandropoulou et al. [10] suggest that the nutritional inadequacy of this pattern might require increased use of dietary supplements or the fortification of staple foods. A clear example of this is the well-established history of food fortification policies in Latin America [81,82], which may explain why low adherence to the EAT-Lancet dietary pattern does not currently reflect a risk of inadequate intake of thiamine, riboflavin, niacin, and folate in the participating countries. The intake of these nutrients is likely being supplied primarily by fortified staple foods (e.g., white rice, wheat, and corn flour) [83], despite these foods not being part of the reference dietary pattern. While the authors of the EAT-Lancet reference diet suggest adjustments to fit sociocultural contexts, the current pattern does not include the option to substitute whole grains with refined grains.

This study has several strengths and limitations to consider when interpreting its results. Strengths include: (1) The 24-hour dietary recall method for food intake data collection is more accurate than the food frequency questionnaire used in similar studies. (2) Micronutrient intake adequacy was evaluated using usual intake from 2 complete days, reducing methodological bias from intrapersonal variability. (3) The large plausible sample size provided precise mean values, identified outliers, and reduced the margin of error, allowing better micronutrient intake estimations in Latin American urban areas. (4) The PHDI scores proportionally and accounts for intermediate intakes of the EAT-Lancet dietary pattern more precisely than other reference diet-based indices [36]. (5) The methodology used to assess the association between adherence to the dietary pattern and the risk of nutrient inade-

Table 5 – Association between high adherence to the Planetary Health Diet Index and nutrient inadequacy of 13 micronutrients among participants in the Latin American Study of Nutrition and Health (2016) (n = 6835).

Nutrient	PR[a]	95% CI	*p*-value[b]	*p*-trend[c]
Vitamins				
Thiamin	0.625	0.239-1.634	.337	.489
Riboflavin	1.351	0.937-1.947	.107	.081
Niacin	0.275	0.058-1.317	.106	.060
Pyridoxine	0.687	0.502-0.939	.019	.009
Folate equivalents	0.378	0.223-0.643	<.001	<.001
Cobalamin	1.800	1.215-2.669	.003	.009
Vitamin C	0.477	0.432-0.526	<.001	<.001
Vitamin A	0.986	0.917-1.060	.695	.509
Vitamin D	1.010	1.001-1.019	.024	.019
Minerals				
Calcium	1.119	1.090-1.149	<.001	<.001
Iron	0.331	0.121-0.906	.031	.070
Magnesium	0.882	0.858-0.908	<.001	<.001
Zinc	0.818	0.688-0.973	.023	.010

PHDI: Planetary Health Diet Index.
Multivariate Poisson regression with robust variance analysis:
[a] Prevalence ratio of nutrient inadequacy for the 5th PHDI quintile vs the 1st PHDI quintile (baseline); adjusted for sex, age, socioeconomic status, and country. Nutrient inadequacy was defined as a Nutrient Adequacy Ratio (NAR) <1.
[b] *p*-value corresponds to the Wald test for the 5th PHDI quintile as a category of the PHDI within each model.
[c] *p*-value for trend corresponds to the linear trend among PHDI quintiles within each model.PHDI quintiles: min–max score/1st: 13.4-36.7; 2nd: 36.8-42.0; 3rd: 42.1-46.8; 4th: 46.9-52.3; 5th: 52.4-82.8. Usual nutrient intakes were energy-adjusted by the nutrient residual model.

quacy is robust. It has been previously used by several authors [59–62]. On the other hand, limitations include the following: (1) The study only included urban areas in 8 Latin American countries, excluding rural areas and other countries in the region, so the data cannot be generalized to all of Latin America. (2) These results should be interpreted within the context of the study design (cross-sectional analysis), and it can assess associations but cannot determine causality. (3) Differences in the characteristics of included and excluded participants based on misreporting of energy intake were identified in 3 countries (Argentina, Peru, and Venezuela) and across low and high physical activity levels. Consequently, these differences should be considered when generalizing the results to these groups. (4) The Nutrition Data System for Research software, used to convert food intake into nutrient values, relies on the USDA National Nutrient Database as its primary source. This database includes nutrient compositions that may differ from those of foods available in Latin America, particularly for ultra-processed foods. This could introduce bias in the estimation of nutrient intake and its respective adequacy or inadequacy. (5) The disaggregation of the ultra-processed foods to include their content of added sugar, vegetable oils, and animal (saturated) fat in the PHDI calculation might be subject to bias. Therefore, this process underwent review by 4 trained nutritionists to minimize errors.

5. Conclusion

The low adherence to the EAT-Lancet dietary pattern in Latin America can be attributed to the region's food culture, which is not fully aligned with the dietary recommendations of the EAT-Lancet Commission. To improve adherence to the EAT-Lancet diet or any other strategy proposed to improve diet quality and sustainability, it is crucial to adapt the proposed diet to better fit the region's food culture, while minimizing its environmental impact as much as possible. Adaptations should include fortified foods, such as white rice, corn, or wheat flour, which are familiar and culturally accepted in Latin America, along with the promotion of other food groups supported by the dietary pattern, such as fruits, vegetables, and legumes. Additionally, it is important to explore food alternatives to replace nuts, seeds, and whole grains, as these are not widely included in the region's food culture.

Other modifications should address specific nutritional gaps in the population. For instance, there is a need to increase the consumption of foods rich in cobalamin, calcium, and vitamin D, which were identified as being at risk in individuals with higher adherence to the reference pattern. Therefore, the development of a Latin American version of the EAT-Lancet diet should emphasize these nutrient-rich foods, such as dairy products or fortified alternatives, while still aligning with the sustainability and health principles promoted by the EAT-Lancet framework.

Author declarations

None.

CRediT authorship contribution statement

Rulamán Vargas-Quesada: Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rafael Monge-**

Rojas: Writing – review & editing, Visualization, Methodology, Conceptualization. **Juan José Romero-Zúñiga:** Writing – review & editing, Methodology. **Raquel Arriola Aguirre:** Writing – review & editing. **Irina Kovalskys:** Writing – review & editing. **Marianella Herrera-Cuenca:** Writing – review & editing. **Lilia Yadira Cortés:** Writing – review & editing. **Martha Cecilia Yépez García:** Writing – review & editing. **Reyna Liria-Domínguez:** Writing – review & editing. **Attilio Rigotti:** Writing – review & editing. **Mauro Fisberg:** Writing – review & editing. **Georgina Gómez:** Writing – review & editing, Supervision, Methodology, Conceptualization.

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Supplementary materials

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