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Fatty acid composition of foods as consumed and population intake in Cuba: A Total Diet Study

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ABSTRACT

Fatty acid composition data reflecting foods as consumed remain limited for many populations. This study characterized fatty acid profiles and estimated population intakes within the Cuban Total Diet Study. Dietary consumption data were obtained from structured 24-h recalls conducted in 450 adults and used to aggregate 107 commonly consumed foods into 17 food groups. Fatty acids were quantified by GC-FID in 48 regional composites representing 16 lipid-containing groups from Western, Central, and Eastern Cuba. Participant-level fatty acid intakes were estimated by linking individual food-group consumption with the corresponding analytically determined composite concentrations. The method provided recoveries of 92.7–105.8%, repeatability of 1.5–3.2%, and LOQs of 0.20–0.43 mg/100 g. Estimated total fatty acid intake was 98.27 ± 2.50 g/day, comprising 38.04 ± 1.57 g/day MUFA, 31.32 ± 1.25 g/day SFA, and 27.45 ± 1.17 g/day PUFA. Fats and oils contributed 40.0% of MUFA, 48.6% of linoleic acid, and 50.4% of α-linolenic acid, whereas fish and seafood supplied 82.6% of EPA and 90.7% of DHA. EPA + DHA intake was 841 ± 87 mg/day, with regional mean estimates ranging from 781 to 975 mg/day. These analytically derived data characterize the fatty acid composition of foods as consumed and provide new information for food-composition databases, dietary surveillance, and population nutritional assessment in Cuba.

1. Introduction

Dietary fatty acids differ substantially in their physiological roles and food sources, making fatty acid composition more informative than total fat intake alone. Linoleic acid (LA; C18:2 n-6) and α-linolenic acid (ALA; C18:3 n-3) are essential fatty acids and precursors of longer-chain polyunsaturated fatty acids (PUFA), including arachidonic acid (AA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA), which participate in membrane structure, cell signaling, and lipid-mediated homeostasis (Saini and Keum, 2018). At the population level, the balance among saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), PUFA, trans fatty acids (TFA), and individual n-3 and n-6 species varies markedly across dietary patterns and food systems (Micha et al., 2014). Accurate characterization of these patterns is therefore fundamental for food-composition databases, dietary surveillance, and evaluation of population fatty acid exposure.

However, fatty acid intake estimates are highly dependent on the quality and representativeness of the underlying food-composition data. Conventional databases may not adequately reflect regional foods, commercial formulations, culinary practices, or the incorporation of oils and other ingredients during preparation. Direct chemical analysis remains the preferred approach for generating high-quality food-composition data, particularly when substantial variability is expected among foods and processing conditions (Mukunzi and Aryee, 2026). Total Diet Studies (TDS) provide a complementary framework by selecting foods according to actual consumption, preparing them as consumed, pooling representative items, and analytically linking their composition with dietary intake data (EFSA; FAO, 2011). This approach reduces the

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disconnect between nutrient concentrations measured in individual raw foods and the chemical composition of the diet actually consumed.

Despite its potential for nutritional assessment, relatively few TDS have characterized detailed fatty acid profiles. The Chinese TDS quantified 62 fatty acids in 192 prepared food composites and demonstrated substantial differences in fat composition and intake across food categories and geographic areas (Pei et al., 2021). Population studies from Europe and other regions have likewise shown considerable variation in the intake and dietary sources of individual fatty acids, particularly LA, ALA, EPA, and DHA (Redruello-Requejo et al., 2023). In Cuba, the TDS framework has recently generated analytical data for essential minerals and amino acids (González et al., 2026, 2025), but a comprehensive analytical assessment of dietary fatty acid composition and intake has not yet been reported.

The present study addresses this gap by characterizing major fatty acid classes and individual fatty acids in 48 food-group composites representing 16 lipid-containing food groups from Western, Central, and Eastern Cuba. Unlike estimates based exclusively on food-composition databases, fatty acid intakes were derived from GC-FID measurements of foods prepared *as consumed* and integrated with population food-consumption data. Beyond estimating national intake, the study quantifies the contribution of individual food groups to SFA, MUFA, LA, ALA, AA, EPA, DPA, and DHA exposure, evaluates geographic variability across the three Cuban regions, and places the resulting intake profile in an international context. This integrated analytical–dietary approach provides the first detailed characterization of the structure, dietary sources, and regional distribution of fatty acid exposure within the Cuban TDS and establishes new composition data for population-level nutritional assessment.

2. Materials and methods

2.1. Study design and dietary assessment

The study was conducted within the framework of the Cuban Total Diet Study (TDS) to characterize the fatty acid composition of foods as consumed and to derive population-level dietary intake estimates. Food-consumption information was obtained from structured 24-h dietary recalls conducted between October 2020 and March 2021 among 450 Cuban adults aged 18–91 years recruited from Western, Central, and Eastern Cuba.

A multistage sampling strategy was used to capture geographic and urban–rural variability. Cuba was first divided into three geographic domains (Western, Central, and Eastern Cuba), after which municipalities were selected within each region and participants were allocated according to the relative proportions of urban and rural residents. Municipalities therefore represented the primary clustering level, whereas geographic region and urban–rural residence defined the principal sampling strata. Because participant allocation followed the underlying regional urban–rural population structure, no additional post-stratification weights were applied in the present analysis. Accordingly, the estimates should be interpreted as representative of the surveyed adult population structure rather than as design-weighted national prevalence estimates.

Dietary records were reviewed for completeness before inclusion. Records associated with acute illness or clearly atypical food intake were excluded (<1%). Foods reported in the recalls were harmonized by food type and preparation form, and mean consumption was calculated as grams per person per day. A total of 107 individual foods accounted for the major components of the habitual diet and were aggregated into 17 TDS food groups according to dietary contribution, culinary use, and physicochemical characteristics (Table S1). The original groups comprised rice; meat; fish and seafood; processed meat products; milk and dairy products; fruits; tubers and starchy vegetables; vegetables; legumes; bread and wheat-flour products; fats and oils; non-alcoholic beverages; alcoholic beverages; sugars and sweets; condiments and sauces; salt; and eggs. Salt was retained in the general TDS design but excluded from fatty acid determination because of its negligible lipid contribution. Consequently, 16 food groups were considered in the present fatty acid study.

All participants provided written informed consent. The study protocol was approved by the Ethics Committee of the Faculty of Medical Sciences of Matanzas, Cuba (approval No. 03112021).

2.2. Regional sampling and preparation of TDS food composites

Food sampling was conducted independently in Western, Central, and Eastern Cuba. Individual foods were purchased from representative retail outlets and included locally marketed products, different commercial brands, and food origins encountered within each region. The sampling strategy was designed to reproduce the foods described in the dietary survey rather than to characterize individual commercial products.

Samples were prepared according to habitual consumption practices before compositing. Inedible portions were removed; fruits and vegetables were washed and peeled when normally consumed peeled; canned foods were drained when appropriate; and foods ordinarily consumed after cooking were boiled, roasted, fried, or otherwise prepared using representative domestic procedures. Recipe ingredients were treated as separate TDS food components rather than incorporated into the composite of the principal food. Thus, oils, condiments, salt, and other ingredients used during preparation were assigned to their respective food groups and were not included in the rice, meat, legume, vegetable, or other corresponding composites. This approach ensured that each ingredient was represented only once in the TDS food basket and avoided double counting during intake estimation.

Within each regional composite, individual foods were combined on an edible, prepared-weight basis according to their relative contribution to mean consumption, as reported in Table S1. Thus, foods with greater consumption contributed proportionally more material to the corresponding analytical composite. For example, the meat composite comprised approximately 60% chicken, 23% pork, 12% beef, and 5% mutton, with these percentages representing the mass contribution of each prepared food to the composite.

The 17 original food groups generated one independent composite in each of the three regions (51 regional TDS composites). Because salt was excluded from lipid analysis, fatty acids were determined in 48 regional composites corresponding to 16 food groups × 3 regions. Each composite was homogenized until visually uniform using a high-speed food homogenizer, subdivided into analytical aliquots in amber or opaque containers, and stored at −20 °C. Samples were thawed at 4 °C and re-homogenized immediately before analytical subsampling. Regional composites represented independent sampling units; replicate injections or repeat extractions from the same homogenate were considered analytical replicates.

2.3. Reagents, standards and preparation of calibration solutions

All solvents used for extraction and derivatization were analytical or chromatographic grade. Diethyl ether, petroleum ether, ethanol (95%, v/v), toluene, chloroform, *n*-hexane, hydrochloric acid, aqueous ammonia, anhydrous sodium sulfate, pyrogallic acid, and boron trifluoride in methanol were used for lipid extraction and methylation.

Fatty acid identity and instrument response were established using certified commercial FAME mixtures covering saturated, cis-monounsaturated, polyunsaturated, trans, and long-chain n-3 fatty acids. Individual standards were used when required to confirm C20:4 n-6, C20:5 n-3, C22:5 n-3, and C22:6 n-3. Stock solutions were maintained in amber glass under refrigerated conditions and working solutions were prepared gravimetrically by serial dilution in *n*-hexane.

Triundecanoin (C11:0 TAG) was used as the extraction and quantification internal standard following AOAC Official Method 996.06. The

Table 1
Analytical performance of the method for selected individual fatty acids in Cuban Total Diet Study samples.

Fatty acid	Linear range (mg/L)	R^2	Recovery (%)	RSDr (%)	RSDip (%)	LOD (mg/100 g)	LOQ (mg/100 g)	U (%)
C16:0	0.50–250	0.9998	97.2–102.8	1.6	2.5	0.06	0.2	4.8
C18:0	0.50–250	0.9997	96.4–103.1	1.8	2.8	0.07	0.23	5.1
C18:1 *cis*-9	0.50–250	0.9999	97.5–102.4	1.5	2.4	0.06	0.2	4.6
C18:2 n-6 (LA)	0.50–250	0.9998	96.8–103.6	1.7	2.7	0.07	0.23	5
C18:3 n-3 (ALA)	0.25–125	0.9995	95.1–104.2	2.2	3.4	0.08	0.27	5.8
C20:4 n-6 (AA)	0.10–75	0.9993	94.3–104.8	2.6	4.1	0.1	0.33	6.6
C20:5 n-3 (EPA)	0.10–75	0.9992	93.5–105.2	2.9	4.5	0.11	0.36	7.1
C22:5 n-3 (DPA)	0.10–50	0.9989	92.7–105.8	3.2	5	0.13	0.43	7.8
C22:6 n-3 (DHA)	0.10–75	0.9991	93.1–105.5	3	4.7	0.12	0.4	7.4

RSDr, relative standard deviation under repeatability conditions; RSDip, relative standard deviation for intermediate precision; LOD, limit of detection; LOQ, limit of quantification; U, expanded measurement uncertainty (k = 2). Recovery values represent the range obtained across the evaluated fortification levels. LA, linoleic acid; ALA, α-linolenic acid; AA, arachidonic acid; EPA, eicosapentaenoic acid; DPA, docosapentaenoic acid; DHA, docosahexaenoic acid.

internal-standard solution was prepared at 5.00 mg/mL in chloroform and stored at 2–8 °C. The use of a TAG internal standard before hydrolysis allowed correction for losses occurring during hydrolysis, solvent extraction, methylation, and transfer rather than only for variability during GC injection. The analytical procedure was based on AOAC 996.06 with adaptations for heterogeneous TDS matrices (AOAC, 2023; Pei et al., 2021).

2.4. Hydrolytic extraction of total fatty acids

The test portion was adjusted according to the expected lipid concentration of each matrix. Approximately 0.1–1.0 g was used for lipid-rich matrices such as fats and oils, whereas up to 10 g was used for low-fat matrices including beverages, fruits, vegetables, and tubers. The objective was to obtain a final FAME concentration within the validated instrumental range.

The homogenized sample was weighed into a 125-mL Erlenmeyer flask and 100 mg pyrogallic acid, 2 mL ethanol (95%, v/v), and 4 mL ultrapure water were added. Pyrogallic acid was included as an antioxidant to minimize oxidative degradation of PUFA during hydrolysis. Subsequently, 2.00 mL C11:0 triundecanoin internal-standard solution was added before any extraction step.

Matrix-dependent hydrolysis was performed according to AOAC 996.06. Milk and dairy composites were treated with 5 mL aqueous ammonia to achieve alkaline hydrolysis, whereas non-dairy matrices were treated with 10 mL hydrochloric acid solution. Samples were mixed thoroughly and incubated in a thermostated water bath at 70–80 °C for 40 min with intermittent agitation. Hydrolysis was followed by cooling to 20–25 °C.

After cooling, 10 mL ethanol (95%, v/v) was added. Lipids were extracted first with 25 mL diethyl ether by mechanical shaking for 3 min and subsequently with 25 mL petroleum ether for an additional 3 min. The complete mixture was transferred to a stoppered separation cylinder and allowed to separate for at least 10 min. The upper organic phase was recovered. The aqueous phase was returned to the extraction flask and subjected to a second extraction using another 25 mL diethyl ether followed by 25 mL petroleum ether under the same conditions.

Organic fractions from both extractions were combined and concentrated to dryness under a gentle nitrogen stream at ≤ 40 °C. The use of low evaporation temperature and nitrogen minimized oxidative and thermal alteration of EPA, DPA, DHA, and other unsaturated fatty acids.

2.5. Preparation of fatty acid methyl esters

The isolated lipid fraction was converted to fatty acid methyl esters using the boron-trifluoride/methanol procedure of AOAC 996.06. The dried lipid residue was dissolved in approximately 2–3 mL chloroform and 2–3 mL diethyl ether, transferred to a screw-cap derivatization vial with a PTFE-lined septum, and evaporated again to dryness under nitrogen at approximately 40 °C.

Two milliliters of 7% BF_3 in methanol and 1.0 mL toluene were added to the residue. Vials were tightly sealed and heated at 100 °C for 45 min, with gentle mixing approximately every 10 min. After methylation, samples were cooled to room temperature and 5.0 mL ultrapure water, 1.0 mL *n*-hexane, and approximately 1 g anhydrous Na_2SO_4 were added. Vials were shaken for 1 min and allowed to separate.

The upper hexane phase containing the FAMEs was transferred to a second vial containing anhydrous Na_2SO_4 to remove residual moisture and subsequently transferred to amber autosampler vials. Extracts were maintained at 4 °C and analyzed within the validated stability period. The procedure followed the hydrolytic-extraction/methylation principle of AOAC 996.06, which is specifically designed to quantify total fatty acids from both free and esterified lipid pools and has previously been applied to prepared TDS food composites (Pei et al., 2021).

2.6. GC-FID separation, identification and quantification

FAME analysis was performed by gas chromatography with flame-ionization detection using a Shimadzu GC-2010 gas chromatograph equipped with an AOC-20s autosampler and AOC-20i automatic injector (Shimadzu, Kyoto, Japan). Separation was achieved on a highly polar Rt-2560 biscyanopropyl capillary column (100 m × 0.25 mm i.d., 0.20 μm film thickness; Restek, Bellefonte, PA, USA). The high-polarity 100-m stationary phase was selected because it provides separation according to carbon chain length, degree of unsaturation, and double-bond geometry and is suitable for resolving cis/trans FAMEs and LC-PUFA in complex food matrices.

The injector temperature was 240 °C and a 1.0-μL aliquot was injected in split mode (30:1). Helium (≥99.999% purity) was used as carrier gas at a constant flow of 1.3 mL/min. The oven was initially maintained at 120 °C for 10 min, increased to 180 °C at 3 °C/min, subsequently increased to 200 °C at 1.5 °C/min and held for 3 min, and finally increased to 225 °C at 2 °C/min and held for 20 min. The FID temperature was maintained at 250 °C. Hydrogen and synthetic air flows were adjusted according to the manufacturer's recommended conditions for stable FID operation.

Individual FAMEs were identified by matching retention times with authenticated standards analyzed under identical chromatographic conditions. Retention-time confirmation was periodically performed using a multi-component FAME reference mixture. Particular attention was given to the chromatographic separation of C18 unsaturated isomers and the LC-PUFA region containing AA, EPA, DPA, and DHA. The Rt-2560 stationary phase has been specifically demonstrated to meet critical AOAC 996.06 requirements for separation of closely eluting FAMEs, including C18:3/C20:1 and C20:3/C20:4 species.

Quantification was performed using the internal-standard approach and experimentally determined response factors. For fatty acid (i), the FAME response factor was calculated using Eq. 1.

$$R_i = \frac{A_{i,std} \times W_{IS,std}}{A_{IS,std} \times W_{i,std}} \quad (1)$$

Where $A_{i,std}$ and $A_{IS,std}$ represent the peak areas of fatty acid *i* and the C11:0 internal standard in the calibration mixture, respectively, and $W_{i,std}$ and $W_{IS,std}$ are their corresponding masses.

The mass of each FAME in the sample was subsequently obtained from the analyte/internal-standard area ratio corrected by (R_i), and converted from methyl ester to the corresponding fatty acid using the molecular conversion factor specified in AOAC 996.06. Final concentrations were calculated relative to sample mass and expressed as g fatty acid/100 g edible portion, *as consumed*.

Total FA was calculated as the sum of all individually quantified fatty acids. Fatty acids were grouped according to chemical structure, and SFA, MUFA, PUFA, n-6 PUFA, n-3 PUFA, and TFA were calculated by summing the concentrations of the individual fatty acids assigned to each class. These parameters therefore represent derived analytical sums rather than independently quantified analytes and were not subjected to separate calibration or fortification experiments. TFA was calculated as the sum of the quantified trans-fatty-acid isomers identified in the chromatographic profile. Detailed interpretation focused on C16:0, C18:0, C18:1 cis-9, C18:2 n-6 (LA), C18:3 n-3 (ALA), C20:4 n-6 (AA), C20:5 n-3 (EPA), C22:5 n-3 (DPA), and C22:6 n-3 (DHA).

2.7. Analytical quality assurance and validation

Analytical performance was evaluated at the individual-fatty-acid level. Table 1 summarizes the validation results for the nine fatty acids selected for detailed quantitative interpretation. Total FA and fatty acid classes (SFA, MUFA, PUFA, n-6 PUFA, n-3 PUFA, and TFA) were subsequently calculated from the quantified individual fatty acids and were therefore treated as derived parameters rather than independently validated analytes.

Analyte-specific calibration curves were prepared at a minimum of six concentration levels. Working ranges were 0.50–250 mg/L for C16:0, C18:0, C18:1 *cis*-9, and LA; 0.25–125 mg/L for ALA; 0.10–75 mg/L for AA, EPA, and DHA; and 0.10–50 mg/L for DPA. Calibration was performed using analyte/internal-standard response ratios and linear regression. Linearity was considered satisfactory when residuals showed no systematic concentration-dependent trend and R^2 was ≥ 0.995.

Trueness was evaluated by matrix fortification at low, intermediate, and high levels distributed across the validated working range. Fortified and corresponding non-fortified matrices were processed through the entire hydrolysis, extraction, derivatization, and GC-FID procedure. Recovery was calculated using Eq. 2.

$$\text{Recovery}(\%) = \frac{C_{\text{spiked}} - C_{\text{native}}}{C_{\text{added}}} \times 100 \quad (2)$$

Six replicate determinations were used to estimate repeatability at representative concentration levels. Repeatability precision was expressed as RSD_r. Intermediate precision RSD_{ip} was evaluated using independent analytical runs performed on different days with freshly prepared working solutions and repeat derivatization of the same representative matrices. The resulting method performance yielded recoveries of 92.7–105.8%, RSD_r values of 1.5–3.2%, and RSD_{ip} values of 2.4–5.0%. Experimentally determined LODs ranged from 0.06 to 0.13 mg/100 g and analyte-specific LOQs ranged from 0.20 to 0.43 mg/100 g. Results below the corresponding analyte-specific LOQ were reported as <LOQ, whereas concentrations equal to or above the LOQ were quantitatively reported.

Each analytical batch began with a solvent blank and included a procedural blank to monitor contamination introduced during extraction and derivatization. A multi-component FAME standard was injected after approximately every 6–8 samples to monitor retention-time stability and detector response. Samples were reanalyzed when retention-time deviations, peak resolution, or quality-control responses fell outside predefined acceptance limits.

Expanded measurement uncertainty was estimated using a bottom-up approach that incorporated the principal contributions from calibration, recovery, repeatability, internal-standard preparation, sample mass, and volumetric operations. Individual relative standard uncertainties were combined according to Eq. 3.

$$u_c = \sqrt{u_{cal}^2 + u_{rec}^2 + u_{prec}^2 + u_{IS}^2 + u_{mass}^2} \quad (3)$$

and expanded uncertainty was calculated using Eq. 4.

$$U = K \times u_c \quad (4)$$

using a coverage factor of $k = 2$, corresponding approximately to a 95% level of confidence. Expanded uncertainties ranged from 4.6% to 7.8%.

2.8. Estimation of fatty acid intake and dietary source contribution

Daily intake of each fatty acid was estimated by linking its analytically determined concentration in each TDS food group with the corresponding consumption using Eq. 5.

$$I_{ij} = \frac{C_{ij} \times F_i}{100} \quad (5)$$

where I_{ij} is the intake of fatty acid *j* contributed by food group *i* (g/day), C_{ij} is the concentration of fatty acid *j* in the corresponding composite (g/100 g edible portion), and F_i is consumption of food group *i* (g/day).

Total national intake was calculated using Eq. 6.

$$EDI_j = \sum_{i=1}^{16} I_{ij} \quad (6)$$

National composition values were obtained from the three regional composites, whereas national food consumption represented the corresponding population estimate. AA, EPA, DPA, and DHA were converted from g/day to mg/day before reporting. EPA + DHA and EPA + DPA + DHA were calculated by direct summation of the corresponding individual fatty-acid estimates.

The proportional contribution of food group *i* to the intake of fatty acid *j* was determined using Eq. 7.

$$\text{Contribution}_{ij}(\%) = \frac{I_{ij}}{\sum_{i=1}^{16} I_{ij}} \times 100 \quad (7)$$

Contributions were normalized independently to 100% for each fatty acid. For graphical clarity, food groups contributing only small proportions were aggregated as "Other foods" in the visualization; all individual food groups were retained in the calculations.

2.9. Regional intake assessment

Regional fatty acid exposure was estimated separately for Western, Central, and Eastern Cuba by combining region-specific food-consumption data with the analytically measured concentration in the corresponding regional composite using Eq. 8.

$$EDI_{rj} = \sum_{i=1}^{16} \frac{C_{rij} \times F_{ri}}{100} \quad (8)$$

where C_{rij} is the concentration of fatty acid *j* in food group *i* from region *r*, and F_{ri} is consumption of the corresponding food group in that region.

To distinguish variation in absolute intake from variation in fatty acid composition, each fatty acid was additionally expressed as a percentage of regional total FA intake. Relative deviation from the national estimate was calculated using Eq. 9.

Table 2
Fatty acid concentrations in food-group composites from the Cuban Total Diet Study.

Food group	Total FA	SFA	MUFA	PUFA	n-6 PUFA	n-3 PUFA	TFA	C16:0
Non-alcoholic beverages	0.090 ± 0.012	0.040 ± 0.006	0.030 ± 0.004	0.020 ± 0.003	0.014 ± 0.002	0.003 ± 0.001	0.001 ± 0.0002	0.025 ± 0.004
Rice	0.380 ± 0.041	0.090 ± 0.011	0.120 ± 0.015	0.170 ± 0.021	0.150 ± 0.019	0.012 ± 0.003	0.002 ± 0.001	0.065 ± 0.008
Milk and dairy products	4.35 ± 0.38	2.82 ± 0.25	1.12 ± 0.13	0.27 ± 0.04	0.180 ± 0.025	0.055 ± 0.009	0.115 ± 0.018	1.28 ± 0.14
Bread and wheat-flour products	2.45 ± 0.27	0.55 ± 0.07	0.77 ± 0.09	1.06 ± 0.13	0.940 ± 0.115	0.080 ± 0.012	0.045 ± 0.008	0.390 ± 0.047
Meat	7.95 ± 0.71	3.06 ± 0.31	3.36 ± 0.34	1.38 ± 0.17	1.020 ± 0.126	0.170 ± 0.026	0.070 ± 0.012	1.78 ± 0.19
Vegetables	0.72 ± 0.09	0.14 ± 0.02	0.24 ± 0.03	0.33 ± 0.05	0.285 ± 0.039	0.038 ± 0.007	0.003 ± 0.001	0.095 ± 0.013
Legumes	1.28 ± 0.14	0.22 ± 0.03	0.32 ± 0.04	0.73 ± 0.09	0.610 ± 0.076	0.095 ± 0.014	0.003 ± 0.001	0.155 ± 0.020
Tubers and starchy vegetables	0.46 ± 0.06	0.10 ± 0.01	0.14 ± 0.02	0.21 ± 0.03	0.185 ± 0.025	0.018 ± 0.004	0.002 ± 0.001	0.072 ± 0.010
Alcoholic beverages	0.025 ± 0.005	0.007 ± 0.002	0.008 ± 0.002	0.009 ± 0.002	0.007 ± 0.002	0.001 ± 0.001	ND	0.005 ± 0.001
Fruits	0.29 ± 0.04	0.065 ± 0.010	0.085 ± 0.012	0.135 ± 0.020	0.105 ± 0.016	0.023 ± 0.005	0.001 ± 0.001	0.043 ± 0.007
Processed meat products	12.80 ± 1.18	4.65 ± 0.48	5.40 ± 0.56	2.47 ± 0.30	1.920 ± 0.228	0.255 ± 0.037	0.160 ± 0.026	2.68 ± 0.29
Fish and seafood	4.95 ± 0.61	1.24 ± 0.16	1.46 ± 0.19	2.20 ± 0.29	0.620 ± 0.083	1.32 ± 0.19	0.018 ± 0.004	0.740 ± 0.091
Sugars and sweets	5.85 ± 0.67	2.14 ± 0.26	2.15 ± 0.25	1.40 ± 0.18	1.230 ± 0.151	0.105 ± 0.017	0.125 ± 0.021	1.27 ± 0.16
Condiments and sauces	7.60 ± 0.91	1.38 ± 0.18	3.08 ± 0.38	3.05 ± 0.41	2.68 ± 0.35	0.30 ± 0.05	0.055 ± 0.010	0.91 ± 0.12
Fats and oils	96.2 ± 2.8	20.4 ± 1.9	42.1 ± 3.4	33.3 ± 2.7	29.7 ± 2.5	3.18 ± 0.34	0.29 ± 0.05	14.1 ± 1.3
Eggs	9.15 ± 0.82	3.02 ± 0.30	3.72 ± 0.38	2.33 ± 0.27	1.78 ± 0.21	0.30 ± 0.04	0.020 ± 0.004	2.05 ± 0.22
Food group	**C18:0**	**C18:1 *cis-9***	**C18:2 n-6 (LA)**	**C18:3 n-3 (ALA)**	**C20:4 n-6 (AA)**	**C20:5 n-3 (EPA)**	**C22:5 n-3 (DPA)**	**C22:6 n-3 (DHA)**
Non-alcoholic beverages	0.008 ± 0.001	0.027 ± 0.004	0.013 ± 0.002	0.002 ± 0.001	<LOQ	<LOQ	<LOQ	<LOQ
Rice	0.014 ± 0.002	0.110 ± 0.014	0.145 ± 0.018	0.010 ± 0.002	<LOQ	<LOQ	<LOQ	<LOQ
Milk and dairy products	0.52 ± 0.06	0.98 ± 0.11	0.165 ± 0.022	0.031 ± 0.006	0.006 ± 0.002	0.003 ± 0.001	0.006 ± 0.002	0.004 ± 0.001
Bread and wheat-flour products	0.110 ± 0.015	0.710 ± 0.086	0.910 ± 0.108	0.073 ± 0.011	0.002 ± 0.001	<LOQ	<LOQ	<LOQ
Meat	0.77 ± 0.09	2.92 ± 0.31	0.960 ± 0.117	0.090 ± 0.014	0.075 ± 0.010	0.012 ± 0.003	0.025 ± 0.005	0.010 ± 0.003
Vegetables	0.025 ± 0.004	0.220 ± 0.031	0.275 ± 0.037	0.035 ± 0.006	<LOQ	<LOQ	<LOQ	<LOQ
Legumes	0.040 ± 0.006	0.290 ± 0.036	0.590 ± 0.073	0.085 ± 0.013	<LOQ	<LOQ	<LOQ	<LOQ
Tubers and starchy vegetables	0.017 ± 0.003	0.130 ± 0.018	0.180 ± 0.024	0.016 ± 0.003	<LOQ	<LOQ	<LOQ	<LOQ
Alcoholic beverages	0.001 ± 0.0003	0.007 ± 0.002	0.007 ± 0.002	0.001 ± 0.001	<LOQ	<LOQ	<LOQ	<LOQ
Fruits	0.012 ± 0.002	0.078 ± 0.011	0.101 ± 0.015	0.021 ± 0.004	<LOQ	<LOQ	<LOQ	<LOQ
Processed meat products	1.18 ± 0.14	4.72 ± 0.51	1.82 ± 0.22	0.115 ± 0.019	0.115 ± 0.016	0.018 ± 0.004	0.035 ± 0.007	0.015 ± 0.004
Fish and seafood	0.260 ± 0.036	1.17 ± 0.15	0.520 ± 0.071	0.075 ± 0.012	0.115 ± 0.019	0.285 ± 0.046	0.145 ± 0.025	0.610 ± 0.094
Sugars and sweets	0.54 ± 0.07	1.94 ± 0.23	1.19 ± 0.15	0.090 ± 0.015	0.002 ± 0.001	<LOQ	<LOQ	<LOQ
Condiments and sauces	0.30 ± 0.04	2.85 ± 0.35	2.59 ± 0.33	0.275 ± 0.044	0.003 ± 0.001	<LOQ	<LOQ	<LOQ
Fats and oils	4.35 ± 0.42	39.2 ± 3.1	28.9 ± 2.4	3.02 ± 0.31	<LOQ	<LOQ	<LOQ	<LOQ
Eggs	0.72 ± 0.08	3.36 ± 0.34	1.62 ± 0.19	0.075 ± 0.012	0.115 ± 0.017	0.012 ± 0.003	0.025 ± 0.005	0.035 ± 0.007

Values are expressed as mean ± SD (g/100 g edible portion, as consumed) across the three regional TDS composites (Western, Central, and Eastern Cuba; n = 3). Total FA, total fatty acids; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; TFA, trans fatty acids; LA, linoleic acid; ALA, α-linolenic acid; AA, arachidonic acid; EPA, eicosapentaenoic acid; DPA, docosapentaenoic acid; DHA, docosahexaenoic acid. Values below the analyte-specific limit of quantification are reported as <LOQ; ND, not detected.

$$\Delta_{rj}(\%) = \left(\frac{\mathrm{EDI}_{rj} - \mathrm{EDI}_{Nj}}{\mathrm{EDI}_{Nj}}\right) \times 100 \quad (9)$$

where EDI_{Nj} represents the corresponding national intake. Positive values therefore represent regional intakes above the national estimate, whereas negative values indicate lower exposure.

For statistically valid regional comparisons, participant-level intake estimates should be calculated by linking each participant's food-group consumption with the corresponding regional composite concentrations. Regional distributions can then be compared using the inferential procedures described below; analytical replicates must not be treated as independent observations.

2.10. Statistical analysis

Fatty acid concentrations are expressed as mean ± standard deviation (SD) of the three regional TDS composites. Regional intake estimates were compared after assessing normality with the Shapiro–Wilk test and homogeneity of variances with Levene's test. Normally distributed data were analyzed by one-way ANOVA followed by Tukey's HSD test; otherwise, the Kruskal–Wallis test followed by Dunn's test with Bonferroni correction was applied. Statistical significance was established at $p < 0.05$. Different superscript letters within the same row indicate significant regional differences. Calculations and graphical analyses were performed using Python 3.13.5.

Regional comparisons were performed using participant-level fatty acid intake estimates. For each participant, consumption of each food group was multiplied by the mean fatty acid concentration measured in

Table 3
Estimated daily intakes of major fatty acid classes and individual fatty acids in the Cuban population and their principal dietary sources.

Fatty acid	Daily intake	Contribution to total FA (%)	Main contributing food groups
Major fatty acid classes			
Total FA	98.27 ± 2.50 g/day	100	Fats and oils; Meats; Milk and dairy products; Meat derivatives
SFA	31.32 ± 1.25 g/day	31.87	Milk and dairy products; Fats and oils; Meats; Meat derivatives
MUFA	38.04 ± 1.57 g/day	38.71	Fats and oils; Meats; Meat derivatives; Milk and dairy products
PUFA	27.45 ± 1.17 g/day	27.94	Fats and oils; Meats; Bread and wheat flour products; Seasoning and dressings
n-6 PUFA	22.32 ± 1.03 g/day	22.72	Fats and oils; Meats; Bread and wheat flour products; Seasoning and dressings
n-3 PUFA	3.72 ± 0.22 g/day	3.78	Fats and oils; Fish and shellfish; Meats; Meat derivatives
TFA	0.938 ± 0.065 g/day	0.95	Milk and dairy products; Meats; Meat derivatives; Fats and oils
Major individual fatty acids			
C16:0	18.47 ± 0.78 g/day	18.79	Fats and oils; Meats; Milk and dairy products; Meat derivatives
C18:0	6.85 ± 0.32 g/day	6.97	Fats and oils; Meats; Milk and dairy products; Meat derivatives
C18:1 *cis*-9	34.31 ± 1.42 g/day	34.91	Fats and oils; Meats; Meat derivatives; Milk and dairy products
C18:2 n-6 (LA)	21.45 ± 0.98 g/day	21.83	Fats and oils; Meats; Bread and wheat flour products; Seasoning and dressings
C18:3 n-3 (ALA)	2.16 ± 0.13 g/day	2.2	Fats and oils; Seasoning and dressings; Meats; Bread and wheat flour products
C20:4 n-6 (AA)	389 ± 29 mg/day	0.4	Meats; Fish and shellfish; Meat derivatives; Egg
C20:5 n-3 (EPA)	285 ± 39 mg/day	0.29	Fish and shellfish; Meats; Meat derivatives
C22:5 n-3 (DPA)	220 ± 24 mg/day	0.22	Fish and shellfish; Meats; Meat derivatives
C22:6 n-3 (DHA)	556 ± 78 mg/day	0.57	Fish and shellfish; Meats; Meat derivatives
Long-chain n-3 PUFA indicators			
EPA + DHA	841 ± 87 mg/day	0.86	Fish and shellfish; Meats; Meat derivatives
EPA + DPA + DHA	1061 ± 91 mg/day	1.08	Fish and shellfish; Meats; Meat derivatives

Values are expressed as mean ± SD. Daily fatty acid intakes were estimated by combining the concentrations measured in the TDS food-group composites with the corresponding mean daily food consumption. Contribution to total FA was calculated relative to the estimated total fatty acid intake (98.27 g/day), after conversion of mg/day values to g/day where applicable. Food groups are listed in decreasing order of contribution to the intake of each fatty acid. Abbreviations are as defined in Table 2.

the corresponding regional TDS composite, and contributions from all food groups were summed to obtain individual daily intake. Thus, the participant, rather than the analytical composite, constituted the observational unit for regional comparisons. The sampling structure was accounted for by retaining geographic/urban–rural stratification and municipality-level clustering; no additional post-stratification weights were applied because participant allocation followed the regional urban–rural population distribution.

3. Results and discussions

3.1. Analytical performance of fatty acid determination

The analytical procedure provided consistent quantitative performance across the chemically heterogeneous matrices represented in the Cuban Total Diet Study (Table 1). Calibration was highly linear over analyte-specific working ranges extending from 0.10 to 50 mg/L for DPA to 0.50–250 mg/L for the major C16–C18 fatty acids, with coefficients of determination of 0.9989–0.9999. Recoveries ranged from 92.7% to 105.8%, indicating limited systematic bias throughout lipid extraction, derivatization, and chromatographic determination. Recovery intervals were narrowest for the quantitatively predominant C16:0, C18:0, C18:1 *cis*-9, and LA, whereas slightly broader ranges were observed for the lower-abundance long-chain PUFA. This behavior is consistent with the greater analytical sensitivity of minor PUFA to sample preparation, derivatization efficiency, and chromatographic resolution. Similar validation studies have emphasized recovery control and separation performance as critical determinants of reliable fatty acid quantification in complex food matrices (Contarini et al., 2013; Juan-Polo et al., 2022).

Precision remained well controlled across the entire analytical panel. RSD_r values ranged from 1.5% to 3.2%, while intermediate precision RSD_{ip} ranged from 2.4% to 5.0%. C18:1 *cis*-9 exhibited the lowest analytical variability, whereas DPA showed the highest RSD_r and RSD_{ip} values. The modest increase in variability from the major C16–C18 fatty acids toward EPA, DPA, and DHA is analytically plausible given their substantially lower abundance and greater dependence on chromatographic resolution. Comparable behavior has been reported for LC-PUFA analysis in seafood matrices, where EPA and DHA generally require more rigorous control of extraction and chromatographic conditions than quantitatively dominant fatty acids (Juárez et al., 2010).

Analytical sensitivity was sufficient to characterize both lipid-rich and low-fat composites. LODs ranged from 0.06 to 0.13 mg/100 g and LOQs from 0.20 to 0.43 mg/100 g, enabling measurement across matrices ranging from beverages to edible oils. Expanded measurement uncertainty increased from 4.6 to 5.1% for the major C16–C18 fatty acids to 7.1–7.8% for EPA and DPA, with DHA at 7.4%. Although these uncertainties are higher than those attainable using higher-order isotope-dilution reference methods developed for highly standardized matrices, for which relative expanded uncertainties of approximately 1–6% have been reported (Lee et al., 2019), they remain appropriate for a multi-matrix TDS application. Taken together, the high linearity, quantitative recovery, low analytical variability, and sub-mg/100 g quantification capability provide a robust basis for generating reliable fatty acid composition data and for propagating these measurements into subsequent population-intake estimates.

3.2. Fatty acid composition and compositional signatures of Cuban TDS food groups

Marked compositional heterogeneity was observed among Cuban TDS food-group composites, with total FA concentrations spanning more than three orders of magnitude, from 0.025 g/100 g in alcoholic beverages to 96.2 g/100 g in fats and oils (Table 2). Fats and oils displayed the most strongly unsaturated profile, with MUFA and PUFA representing approximately 43.8 and 34.6% of total FA, respectively. C18:1

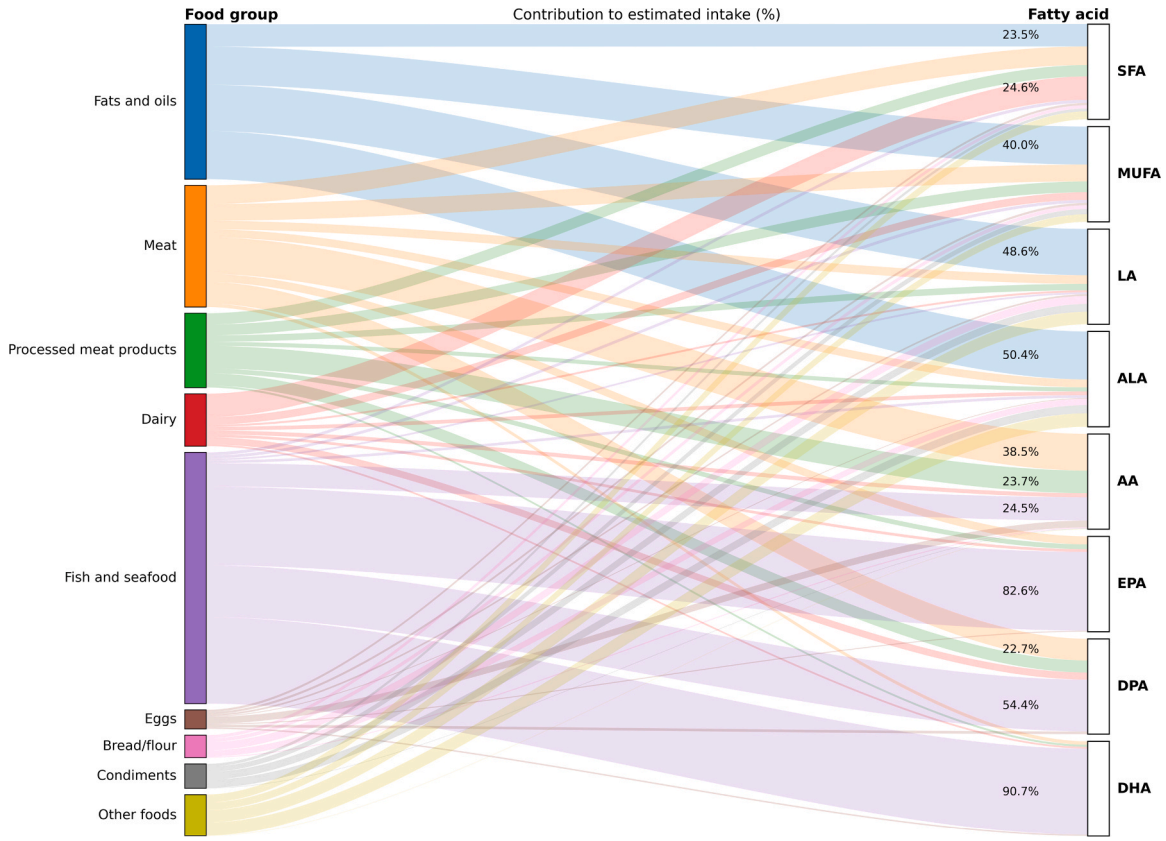

Fig. 1.

cis-9 (39.2 g/100 g), LA (28.9 g/100 g), and ALA (3.02 g/100 g) were the dominant individual species, indicating that the lipid profile of this group was characterized predominantly by C18 unsaturated fatty acids typical of vegetable-oil-containing foods. The relative abundance of oleic, linoleic, and α-linolenic acids is widely recognized as a major determinant of the compositional differentiation of edible oils and can reflect differences in botanical origin and processing history.

Animal-derived foods exhibited distinctly different lipid fingerprints. Milk and dairy products were strongly SFA-dominated, with SFA accounting for approximately 65% of total FA and C16:0 and C18:0 representing the principal quantified saturated components. This pattern is consistent with large surveys of bovine milk showing palmitic acid as the predominant SFA and oleic acid as the principal unsaturated FA (O'Donnell-Megaro et al., 2011). Meat and processed meat products displayed a more balanced SFA–MUFA composition, characterized by high C18:1 *cis*-9 together with substantial C16:0 and C18:0 concentrations. Comparable profiles have been reported for meat lipids, where these fatty acids account for a large proportion of total intramuscular and adipose lipids (Andueza et al., 2019; Turk and Smith, 2009). Processed meat products additionally contained the highest TFA concentration among the animal-derived composites (0.160 g/100 g), although TFA remained a minor component relative to their total FA content.

Fish and seafood exhibited the most distinctive LC n-3 signature. Although total FA concentration was moderate (4.95 g/100 g), n-3 PUFA reached 1.32 g/100 g, including 0.285 g/100 g EPA, 0.145 g/100 g DPA, and 0.610 g/100 g DHA. EPA + DPA + DHA therefore accounted for approximately 79% of the measured n-3 fraction, clearly differentiating marine foods from all other TDS groups. Such enrichment is consistent with detailed marine-food composition studies in which EPA and particularly DHA are prominent components of the PUFA fraction but show substantial species-dependent variation (Rincón-Cervera et al., 2019). Eggs displayed a different animal-derived PUFA signature, combining relatively high LA (1.62 g/100 g) with AA (0.115 g/100 g) and measurable DHA (0.035 g/100 g), reflecting the coexistence of n-6 and LC n-3 fatty acids within yolk lipids.

Plant-derived low- and intermediate-fat groups were differentiated primarily by relative PUFA enrichment rather than absolute lipid concentration. Legumes contained only 1.28 g/100 g total FA, yet PUFA represented approximately 57% of their lipid fraction and was dominated by LA (0.590 g/100 g) and ALA (0.085 g/100 g), consistent with PUFA-rich profiles reported for several legume species (Caprioli et al., 2016). Bread and wheat-flour products and condiments and sauces also showed LA-dominated profiles, consistent with the fatty acid composition of cereal- and vegetable-derived lipid sources.

3.3. Population fatty acid intake and dietary source architecture

Integration of the analytically determined fatty acid concentrations with mean food-consumption data yielded an estimated total FA intake of 98.27 ± 2.50 g/day in the Cuban population (Table 3). MUFA represented the largest fraction (38.04 ± 1.57 g/day; 38.7% of total FA), followed by SFA (31.32 ± 1.25 g/day; 31.9%) and PUFA (27.45 ± 1.17 g/day; 27.9%). Among individual fatty acids, C18:1 *cis*-9 was quantitatively predominant (34.31 ± 1.42 g/day), followed by LA (21.45 ± 0.98 g/day), C16:0 (18.47 ± 0.78 g/day), and C18:0 (6.85 ± 0.32 g/day). Thus, population lipid exposure was dominated by a relatively restricted set of C16–C18 fatty acids, a pattern also observed in large dietary datasets where palmitic, stearic, oleic, and linoleic acids account for most total fatty acid intake (Kelly et al., 2022).

The dietary-source network integrated information from food-group fatty acid composition and habitual consumption, rather than analytical concentration alone (Fig. 1). Fats and oils were the principal source of MUFA (40.0%), LA (48.6%), and ALA (50.4%), whereas SFA intake was distributed across several food groups, with milk and dairy products (24.6%) and meat (19.5%) among the leading contributors. AA exhibited a similarly diversified animal-food origin: meat supplied 38.5%, fish

Table 4
Regional variation in estimated daily fatty acid intake and relative fatty acid distribution across Cuba.

Fatty acid	Unit	Western	Central	Eastern
Major fatty acid classes				
Total FA	g/day	92.25 ± 24.96 [b]	108.31 ± 27.49 [a]	105.68 ± 25.30 [a]
SFA	g/day	29.73 ± 8.25 [b]	33.89 ± 8.17 [a]	33.30 ± 7.72 [a]
MUFA	g/day	35.57 ± 10.14 [b]	42.18 ± 11.49 [a]	41.07 ± 10.84 [a]
PUFA	g/day	25.56 ± 7.43 [b]	30.67 ± 8.75 [a]	29.76 ± 7.88 [a]
n-6 PUFA	g/day	20.76 ± 6.14 [b]	25.23 ± 7.57 [a]	24.12 ± 7.02 [a]
n-3 PUFA	g/day	3.47 ± 1.73 [b]	3.95 ± 1.75 [a]	4.10 ± 1.73 [a]
TFA	g/day	0.89 ± 0.28 [b]	1.06 ± 0.30 [a]	0.99 ± 0.27 [a]
Major individual fatty acids				
C16:0	g/day	17.46 ± 4.72 [b]	20.11 ± 4.82 [a]	19.73 ± 4.58 [a]
C18:0	g/day	6.49 ± 1.82 [b]	7.41 ± 1.78 [a]	7.33 ± 1.75 [a]
C18:1 *cis*-9	g/day	32.07 ± 9.22 [b]	38.13 ± 10.57 [a]	37.03 ± 9.98 [a]
LA	g/day	19.94 ± 5.93 [b]	24.27 ± 7.35 [a]	23.18 ± 6.83 [a]
ALA	g/day	2.01 ± 0.60 [b]	2.45 ± 0.77 [a]	2.33 ± 0.69 [a]
AA	mg/day	366 ± 125 [b]	397 ± 77 [ab]	430 ± 132 [a]
EPA	mg/day	267 ± 74 [b]	267 ± 56 [ab]	329 ± 176 [a]
DPA	mg/day	208 ± 72 [b]	215 ± 62 [ab]	248 ± 75 [a]
DHA	mg/day	521 ± 141[b]	515 ± 76 [ab]	645 ± 123 [a]
Long-chain n-3 PUFA indicators				
EPA + DHA	mg/day	788 ± 85 [b]	781 ± 101 [ab]	975 ± 119 [a]
EPA + DPA + DHA	mg/day	996 ± 154 [b]	996 ± 161 [ab]	1223 ± 132 [a]

Values are expressed as mean ± SD for Western, Central, and Eastern Cuba. Different superscript letters within the same row indicate significant differences among regions ($p < 0.05$). Abbreviations are as defined in Table 2.

and seafood 24.5%, and processed meat products 23.7%. These results indicate that the major C18 unsaturated fatty acids were largely associated with vegetable-fat-containing food groups, whereas SFA and AA showed broader contributions from animal-derived matrices. Importantly, the TDS approach integrates analytically determined fatty acid concentrations with population food-consumption data while maintaining recipe ingredients as separate food-group contributions, thereby avoiding double counting in source attribution. A comparable analytical-to-intake strategy has been applied in the Chinese Total Diet Study (Pei et al., 2021).

A contrasting source structure was observed for LC n-3 PUFA. Estimated EPA, DPA, and DHA intakes were 285 ± 39, 220 ± 24, and 556 ± 78 mg/day, respectively, yielding 841 ± 87 mg/day for EPA + DHA and 1061 ± 91 mg/day for EPA + DPA + DHA. Fish and seafood supplied 82.6% of EPA, 54.4% of DPA, and 90.7% of DHA, indicating substantially greater source concentration than for SFA, MUFA, LA, or ALA. A similarly strong dependence of EPA and DHA intake on marine foods has been documented in the Spanish ANIBES population (Redruello-Requejo et al., 2023). The Cuban TDS therefore reveals two distinct dietary-source architectures: a broadly distributed supply of the quantitatively predominant C16–C18 fatty acids and a highly concentrated marine-food contribution to LC n-3 PUFA intake. This concentrated source pattern provides a plausible explanation for the greater regional variability observed for LC n-3 PUFA, although the present study was not designed to establish causal mechanisms underlying regional differences.

From a public-health perspective, the observed fatty acid intakes can be contextualized against international dietary recommendations. WHO recommends limiting SFA to no more than 10% of total energy intake and TFA to no more than 1% of total energy intake, whereas the FAO expert consultation established an acceptable macronutrient distribution range of 6–11% of energy for total PUFA (FAO, 2008; WHO, 2023). Because total energy intake was not available in the present dataset, formal assessment of compliance with these energy-based recommendations was not possible. For contextual purposes only, assuming a 2000-kcal diet, the WHO limits would correspond to approximately 22.2 g/day of SFA and 2.2 g/day of TFA, while the FAO PUFA range would correspond to approximately 13.3–24.4 g/day. Against these illustrative values, the Cuban estimates of approximately 31.3 g/day SFA and 27.5 g/day PUFA would be above the corresponding reference levels, whereas TFA intake (approximately 0.94 g/day) would remain below the 1%-energy equivalent. In contrast, EPA + DHA intake was estimated at 841 mg/day, more than three times the 250 mg/day intake recommended for healthy adults by FAO and established as an adequate intake by EFSA (EFSA Panel, 2010; FAO, 2008). This value also falls within the 0.25–2.0 g/day EPA + DHA range considered compatible with a healthy adult diet by the FAO expert consultation. These comparisons should be interpreted cautiously because the energy-based reference values cannot be directly applied without individual total-energy intake data.

3.4. Regional variability in dietary fatty acid intake

A clear geographic gradient was observed in absolute fatty acid intake across Cuba (Table 4; Fig. 2). Western Cuba consistently showed the lowest estimates, with total FA intake of 92.25 g/day compared with 108.31 and 105.68 g/day in Central and Eastern Cuba, respectively. Similar differences were observed for the major lipid classes, with Western intakes of SFA, MUFA, and PUFA approximately 16% below the corresponding national estimates, whereas Central and Eastern values were generally 6–10% higher. Despite these differences in absolute intake, the relative distribution of the major classes remained remarkably stable: SFA represented 31.4–32.4% of regional total FA, MUFA 38.4–39.0%, and PUFA 27.7–28.2%. Thus, geographic variation in overall lipid exposure occurred largely without major displacement of the underlying SFA–MUFA–PUFA balance. This pattern is consistent with differences in the amounts of lipid-containing foods consumed across regions, while the overall SFA–MUFA–PUFA distribution remained comparatively stable. Geographic heterogeneity in total fat and individual fatty acid exposure has also been observed in national dietary surveillance and TDS studies, reflecting differences in food availability, culinary practices, and habitual consumption patterns (Micha et al., 2014; Pei et al., 2021).

The relative stability of the major fatty acid classes contrasted sharply with the variability of LC n-3 PUFA. EPA intake ranged from 139 mg/day in Western Cuba to 434 mg/day in Central Cuba, while DHA ranged from 254 to 869 mg/day. Consequently, EPA + DHA intake differed more than threefold between these regions (788 vs. 781 mg/day), with Eastern Cuba showing an intermediate estimate of 975 mg/day. Relative to the national values, Western Cuba was approximately 51% lower for EPA and 54% lower for DHA, whereas Central Cuba was approximately 52 and 56% higher, respectively. DPA showed the same directional pattern, although with a somewhat smaller amplitude. AA also varied appreciably, from 281 mg/day in Western Cuba to 475 mg/day in Central Cuba, showing greater regional heterogeneity for fatty acids supplied by a more restricted set of animal-derived foods. In contrast, C16:0, C18:0, C18:1 *cis*-9, LA, and ALA varied considerably less and preserved relatively similar contributions to total regional FA intake.

This disproportionate variability of LC n-3 PUFA is consistent with the dietary-source architecture identified in Section 3.3. Given that fish and seafood accounted for 82.6% of EPA and 90.7% of DHA intake, the concentration of these fatty acids in a limited food-source base provides a plausible explanation for their greater regional variability compared

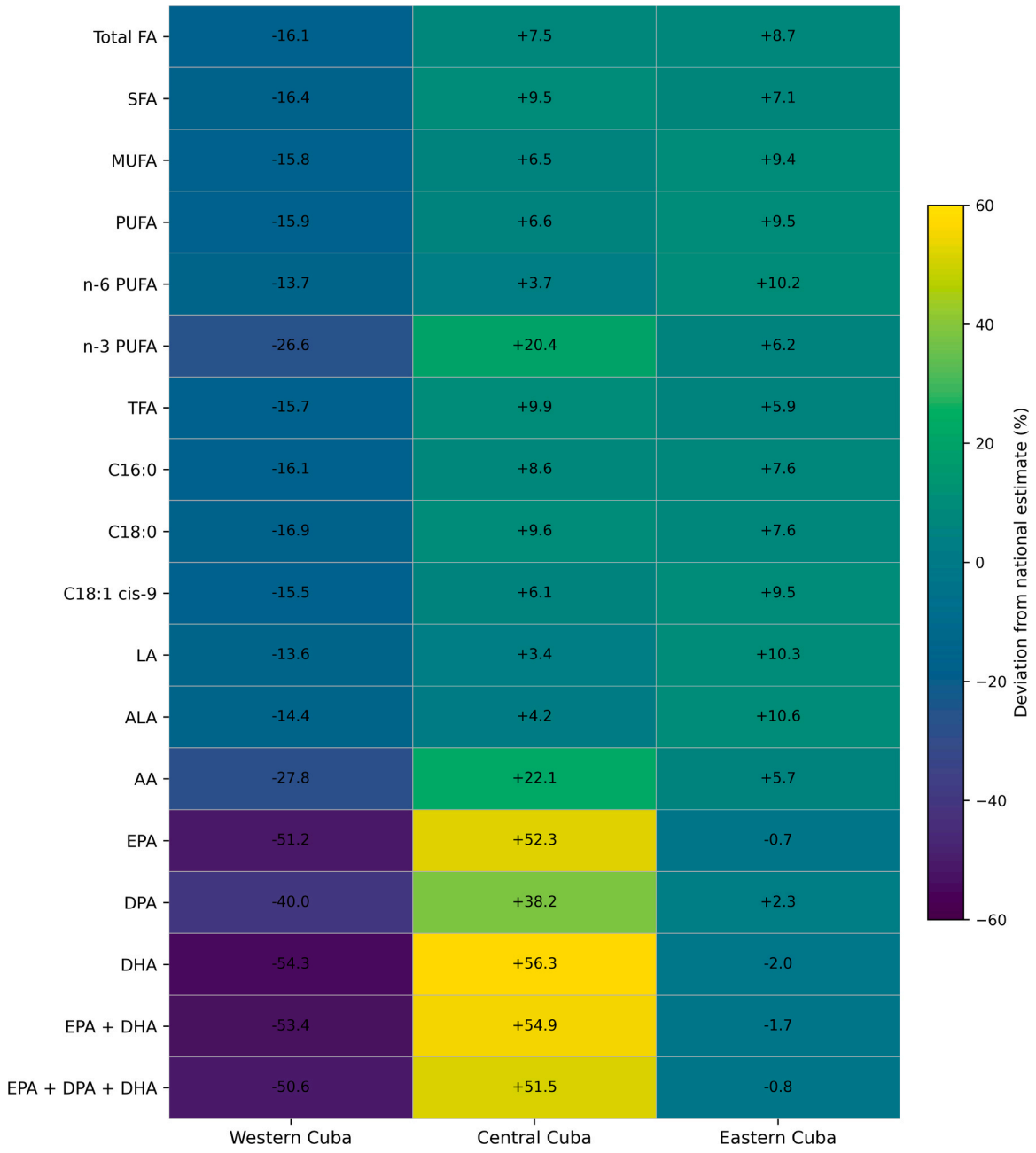

Fig. 2. Regional deviations in estimated fatty acid intake across Cuba. Abbreviations are as defined in Table 2.

with fatty. Geographic variation in fish consumption is well established: the EPIC multicentre study reported approximately six- to sevenfold differences in total fish intake among European populations, together with marked regional differences in fatty-fish and seafood consumption (Welch et al., 2002). Similarly, global dietary analyses have shown far greater geographic dispersion for seafood-derived n-3 fatty acids than for many major dietary fats, with estimated seafood n-3 intake varying from only a few milligrams to several grams per day across countries (Micha et al., 2014). The Cuban results therefore indicate that national mean values adequately describe the broad SFA–MUFA–PUFA structure of the diet but conceal substantial geographic heterogeneity in LC n-3 PUFA exposure. This distinction is relevant when interpreting national fatty acid estimates, because nutrients supported by a narrow food-source base are inherently more sensitive to regional differences in food availability and consumption than fatty acids distributed across multiple dietary groups.

3.5. International context and overall interpretation of Cuban fatty acid intake

The Cuban fatty acid intake profile occupied a distinct position among the selected international populations summarized in Table 5. Total FA intake (98.27 g/day) was comparable to that reported for Spain (100.7 g/day), lower than the Danish estimate (111 g/day), but higher than values reported for the United Kingdom, France, United States, Germany, Australia, Japan, and South Korea. However, the most informative differences concerned fatty acid composition rather than total intake alone. Cuban SFA intake (31.32 g/day) was close to estimates from Spain (32.5 g/day), France (31.8 g/day), and Germany (32.1 g/day), whereas MUFA intake (38.04 g/day) was relatively high among the populations considered. PUFA intake showed an even more distinctive pattern, reaching 27.45 g/day in Cuba compared with approximately 5–17 g/day in most selected studies. This difference was largely associated with the high estimated intake of LA (21.45 g/day),

Table 5
International comparison of reported absolute daily fatty acid intakes in adult populations from selected countries.

Country	Total FA (g/d)	SFA (g/d)	MUFA (g/d)	PUFA (g/d)	C16:0 (g/d)	C18:0 (g/d)	C18:1 cis-9 (g/d)	LA (g/d)	ALA (g/d)	AA (mg/d)	EPA (mg/d)	DPA (mg/d)	DHA (mg/d)	References
Cuba	98.27	31.32	38.04	27.45	18.47	6.85	34.31	21.45	2.16	389	285	220	556	Present study
United Kingdom	72.4	26.8	26.2	12.8	13.45	5.2	24.2	9.67	1.58	110	30	60	180	(Kelly et al., 2022)
Spain	100.7	32.5	46.2	13.2	14.6	5.9	39.6	10.8	1.3	200	160	40	330	(Alcubierre et al., 2020; González-Rodríguez et al., 2013; Redruello-Requejo et al., 2023)
France	83	31.8	29.9	12.4	16.1	7.2	23.7	9.2	0.90	174	132	64	246	(Kesse-Guyot et al., 2012; Tressou et al., 2016)
United States	76.8	24.8	28.4	16.6	13.8	6.3	26.4	14.7	1.45	120	37	22	79	(Chang et al., 2014; Church et al., 2021; Raatz et al., 2017)
Germany	76.6	32.1	26.8	12.6	15.5	6.79	23.4	10.8	1.29	230	130	60	210	(Linseisen et al., 2003; Nimptsch et al., 2010)
Japan	50.7	13.7	18.1	12.3	10.5	3.69	16.4	9.4	1.5	160	330	105	550	(Murai et al., 2024; Sasaki et al., 2003)
South Korea	48.0	9.9	8.1	5.2	4.981	1.973	6.23	3.815	0.517	44	131	29	249	(Lee and Kim, 2023; Park et al., 2024)
Australia	71.1	26.5	27.2	11.1	16.5	8.4	26.7	10.8	1.17	150	55	26	120	(Aridi et al., 2020; Bennie et al., 2015; Nikodijevic et al., 2020)
Denmark	111	45	41	17	20	6	28	12.5	2.1	200	177	62	358	(Graff et al., 2024)

Values represent reported mean or representative daily intakes in adult populations from the indicated studies. When a single publication did not provide the complete fatty acid profile, complementary studies from the same country were used to populate individual fatty acid values; all contributing sources are identified in the References column. Abbreviations are as defined in Table 2.

while ALA intake (2.16 g/day) was also at the upper end of the reported range. Population studies from the United Kingdom and Spain similarly demonstrate that substantial variation in individual fatty acid intake can arise from differences in both the composition of the food supply and the relative contribution of oils, cereals, animal foods, and mixed dishes (Kelly et al., 2022; Redruello-Requejo et al., 2023).

Long-chain n-3 PUFA provided an additional distinguishing feature. The Cuban estimates of EPA and DHA were 285 and 556 mg/day, respectively, corresponding to approximately 841 mg/day of EPA + DHA. Among the populations included in Table 5, this combined intake was substantially higher than estimates reconstructed for the United Kingdom, France, United States, Germany, South Korea, Australia, Spain, and Denmark, and was most comparable to the relatively high marine n-3 intake reported for Japan. The elevated Cuban estimate is consistent with the compositional and source-attribution results of the present TDS, in which fish and seafood were strongly enriched in EPA and DHA and accounted for 82.6 and 90.7% of their respective population intakes. Conversely, populations with lower habitual seafood consumption frequently exhibit substantially lower EPA and DHA exposure. For example, detailed French dietary assessment identified inadequate LC n-3 intake in a large proportion of adults and demonstrated a strong positive association between fish consumption and EPA/DHA intake (Tressou et al., 2016).

These international contrasts should nevertheless be interpreted as contextual rather than direct country rankings. The studies summarized in Table 5 differ in survey period, age distribution, dietary assessment methodology, food-composition databases, analytical coverage, and treatment of individual fatty acids. The UK Biobank estimates, for example, were derived from repeated web-based 24-h assessments linked to food-composition databases, whereas the present Cuban estimates combine measured concentrations in prepared TDS composites with population consumption data. Similar methodological heterogeneity exists across the remaining national studies and may account for part of the observed differences, particularly for minor fatty acids such as EPA, DPA, and DHA were supplied by a much narrower dietary source base and showed greater geographic variability.

Taken together, the results reveal a Cuban dietary lipid pattern characterized by relatively high MUFA and PUFA exposure, substantial LA and ALA intake, and a comparatively strong supply of marine LC n-3 PUFA. At the same time, the study demonstrates that national averages conceal an important structural feature: while the predominant C16–C18 fatty acids are supplied by multiple food groups and show comparatively stable regional distributions, EPA, DPA, and DHA depend on a much narrower dietary source base and consequently display pronounced geographic variability. The integration of analytical food-composition data, source attribution, and regional exposure provides a more informative description of the Cuban fatty acid supply than could be obtained from national mean intake values alone.

Several limitations should be considered when interpreting these findings. Dietary intake was derived from 24-h recall data, which are subject to day-to-day variability and potential underreporting, and no formal energy-based assessment of misreporting was available. In addition, dietary data were collected between October 2020 and March 2021, a period that did not cover a complete annual cycle and overlapped with the COVID-19 pandemic; therefore, seasonal variation and temporary changes in food availability or consumption patterns cannot be excluded. From an analytical perspective, fatty acid composition was represented by one composite per food group and region, limiting the ability to characterize within-region food-composition variability. Moreover, the corresponding regional composite concentration was applied to all participants within that region when estimating intake, which may attenuate individual-level variability. Consequently, national and regional estimates should be interpreted as population-level approximations rather than precise measures of individual habitual intake.

4. Conclusions

This study provides an analytically grounded characterization of the fatty acid composition of representative Cuban Total Diet Study food-group composites and links these data directly to population intake estimates. The major food groups exhibited clearly differentiated lipid signatures: fats and oils were dominated by C18 unsaturated fatty acids, dairy products showed a predominantly saturated profile, meat and processed meat products displayed mixed SFA–MUFA patterns, and fish and seafood were distinguished by their marked enrichment in EPA, DPA, and DHA.

At the population level, MUFA represented the largest fraction of total fatty acid intake, followed by SFA and PUFA, while C18:1 *cis*-9, LA, and C16:0 accounted for most individual fatty acid exposure. Dietary-source analysis showed that major C16–C18 fatty acids were supplied by multiple food groups, whereas LC n-3 PUFA depended predominantly on fish and seafood. This narrow source base was accompanied by greater geographic variability, particularly for EPA, DPA, and DHA, despite a comparatively stable regional SFA–MUFA–PUFA distribution. International comparisons further indicated that the Cuban profile is characterized by relatively high PUFA and marine n-3 exposure, although methodological differences among dietary surveys preclude direct country ranking. Overall, the integration of analytically determined composition, food-consumption data, source attribution, and regional analysis provides a robust framework for describing the Cuban dietary fatty acid supply and generates compositional information of relevance for future food-composition databases, dietary surveillance, and population-level nutritional assessment.

CRediT authorship contribution statement

Luisbel González: Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Antonio Pérez-Torres:** Writing – review & editing, Methodology, Investigation, Formal analysis. **Ociel Muñoz-Fariña:** Writing – review & editing, Validation, Methodology, Investigation. **Alexandra González-Esparza:** Writing – review & editing, Investigation, Formal analysis. **Reinier Fernández-López:** Writing – review & editing, Visualization, Investigation, Formal analysis. **Olman Gómez-Espinoza:** Writing – review & editing, Investigation, Data curation. **Yenisleidys Fernández:** Writing – review & editing, Validation, Methodology, Investigation.

Ethical approval

All participants provided informed written consent for their involvement in the study, and approval was obtained from the Ethics Committee of the Faculty of Medical Sciences of Matanzas, Cuba (03112021).

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jfca.2026.109684.

Data availability

Data will be made available on request.

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