Dietary polyphenol intake and their major food sources in the Mexican Teachers' Cohort

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Abstract

Several descriptive studies on the intake of polyphenols, mostly flavonoids, have been published, especially in Europe and the USA, but insufficient data are still available in Latin-American countries, where different types of foods are consumed and different dietary habits are observed. The goal of this cross-sectional study was to estimate dietary intakes of polyphenols, including grand total, total per classes and subclasses and individual compounds, and to identify their main food sources in Mexican women. The Mexican Teachers' Cohort includes 115 315 female teachers, 25 years and older, from twelve states of Mexico, including urban and rural areas. Dietary data were collected in the period 2008–2011 using a validated FFQ, and individual polyphenol intake was estimated using food composition data from the Phenol-Explorer database. Median total polyphenol intake was the highest in Baja California (750 mg/d) and the lowest in Yucatan (536 mg/d). The main polyphenols consumed were phenolic acids (56·3–68·5 % total polyphenols), followed by flavonoids (28·8–40·9 %). Intake of other polyphenol subclasses (stilbenes, lignans and others) was insignificant. Coffee and fruits were the most important food sources of phenolic acids and flavonoids, respectively. Intake of a total of 287 different individual polyphenols could be estimated, of which forty-two were consumed in an amount ≥1 mg/d. The most largely consumed polyphenols were several caffeoylquinic acids (ranging from 20 and 460 mg/d), ferulic acid, hesperidin and proanthocyanidins. This study shows a large heterogeneity in intakes of individual polyphenols among Mexican women, but a moderate heterogeneity across Mexican states. Main food sources were also similar in the different states.

Key words: Polyphenols: Dietary intakes: Food sources: Mexico

Epidemiological studies have suggested that polyphenols may play a role against chronic diseases, such as cardiovascular diseases[1], diabetes[2], some cancers[3] and total mortality[4,5]. Dietary polyphenols comprise a large family of >500 different compounds with highly diverse structures and are divided into four main classes: flavonoids, phenolic acids, stilbenes and lignans[3]. Their bioavailability and biological properties vary to a great extent and are affected by their chemical structure[6]. Therefore, it is relevant to take into account the heterogeneity of the intake of individual polyphenols when investigating their health effects.

Polyphenols exclusively occur in plant-based foods, such as fruits, vegetables, nuts, legumes, cereals, cocoa and their derived beverages, such as coffee, tea and wine[7]. Polyphenol content is highly variable, both qualitatively and quantitatively.

Some polyphenols are generally distributed in the plant kingdom, whereas others are characteristic to specific foods[8]. Food composition also varies depending on plant variety, geographical area, state of maturity at harvest and food processing and cooking[8,9].

Phenol-Explorer (www.phenol-explorer.eu)[10] is a comprehensive food composition database on all known dietary polyphenols. Since its initial publication in 2009, Phenol-Explorer has been used to estimate the intake of all known individual polyphenols in European adults and the elderly[7,11–15]. However, no similar studies have been conducted in Latin-American countries, where different foods are consumed (such as tropical fruit and vegetables) and different dietary habits are observed, except in Brazil[16]. Intakes of three flavonoid subclasses, cinnamic acids and lignans were

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estimated in two Mexican studies[17,18] using the US Department of Agriculture (USDA) databases[19]. The Mexican Teachers' Cohort (MTC) study offers a unique opportunity to estimate the intake of all individual polyphenols and their main food sources, and to compare these intakes among different Mexican states, as well as between rural and urban areas, using the same dietary assessment methodology. Our hypothesis was that in Mexico there is a north to south westernisation gradient, and westernised diets are less abundant in fruit and vegetables, and therefore in polyphenols. A similar hypothesis was believed for rural v. urban areas, where the adherence of westernised diets is higher.

Methods

The MTC study is a cohort of 115 315 female teachers over 25 years from twelve states of Mexico from both urban and rural schools[20]. The main objective of the cohort is to evaluate the relationships between diet, lifestyle and environmental factors, and the incidence of cancer and chronic diseases in Mexican women. The study started in 2006 enrolling teachers from two states (Veracruz and Jalisco), and in 2008–2011 ten others states (Baja California, Chiapas, Mexico City, Durango, Estado de México, Guanajuato, Hidalgo, Nuevo León, Sonora and Yucatán) were added. A total of 106 466 participants with available dietary data were included in this cross-sectional analysis.

The study research was conducted according to the Declaration of Helsinki and was approved by the Institutional Review Board at the Mexican National Institute of Public Health (INSP) and by the International Agency for Research on Cancer Ethics Committee. All participants provided written informed consent for future use of biological specimens and questionnaire data.

Dietary and lifestyle information

The habitual diet of the preceding year was assessed using a self-administered semi-quantitative FFQ, which included 140 food items with their standard portion size[21]. The list of food items was based on the Mexican version of the FFQ developed by Willett[22] and updated with food items from the Mexican National Health Survey[23]. The FFQ was validated among 134 women living in Mexico City, comparing two FFQ administered by an interviewer at an interval of approximately 1 year to four 4-d 24-h dietary recalls at 3-month intervals[24].

Data on demographics, socio-economic status (SES), reproductive history, clinical history, physical activity, smoking history and early-life risk factors were collected at baseline through a self-administered questionnaire[20]. SES was based on whether the participant had the following items: telephone, mobile telephone, car, computer, vacuum cleaner, microwave oven and internet access (low SES: ≤3 items, medium: SES 4–5 items, high SES: 6+ items). A plastic measuring tape and a short set of instructions were provided to standardise self-reported anthropometric measures (height, weight, waist and hip circumference). BMI was calculated as weight (kg) per height (m) squared. We evaluated the validity of self-reported anthropometry in this population in a subset of 3413

participants. Standardised technician measurements were well correlated with self-reported weight (r 0·2), height (r 0·86) and waist circumference (r 0·78)[25].

Food composition database on polyphenols

Phenol-Explorer database provides data on 502 polyphenol compounds in 452 raw plant-based foods[10]. All animal foods that contain none or only traces of plant polyphenols were excluded. Some typical Mexican foods contained in the FFQ were not present in Phenol-Explorer. For some of them (mamey, zapote, papaya, sweet potato and prickly pears), we found some polyphenol content data in the literature, but not for others (nopal, guava, jicama and squash blossoms). For these foods, polyphenol composition data were not extrapolated from other similar foods, because large differences in their composition can be found between members of the same botanical family[8].

Phenol-Explorer contains data on all polyphenol classes, such as flavonoids, phenolic acids, stilbenes and lignans[10]. Total polyphenol content was calculated as the sum of individual compounds analysed by chromatography without hydrolysis. Polyphenol contents were expressed as glycosides and esters, as present in nature (mg/100 g fresh weight). Proanthocyanidin (PA) dimer data were obtained by chromatography without hydrolysis; however, for PA with a polymerisation degree higher than two (PA trimers, PA 4–6-mers, PA 7–10-mers and PA polymers (>10-mers)), data obtained by normal-phase HPLC were used.

For foods that contained polyphenols linked to the food matrix and only solubilised and quantified after basic or acid hydrolysis, content values obtained by chromatography after hydrolysis were used, as lignans in all foods, ellagic acid in walnuts and hydroxycinnamic acids in cereals, legumes and olives[10]. Moreover, some missing values from orange fruit and breakfast cereals were extrapolated from orange juice and wheat flour, respectively. The effect of food cooking and processing was considered applying individual retention factors from Phenol-Explorer[26].

Statistical analyses

Dietary polyphenol intakes by state were presented as medians and 25th and 75th percentiles, and geometric means because their distributions were skewed. The contribution of each polyphenol class, subclass and family to the total intake of both classes and total polyphenols was calculated as a percentage of geometric means. The contribution of each food group to the intake of total polyphenols and totals per polyphenol classes was also calculated as a percentage. Moreover, main food source groups and contribution to total polyphenol intake by state were computed. Polyphenol intakes were also compared between different states, groups of age, BMI, SES, smoking status, rural and urban area and physical activity index categories. In addition, predictors of specific polyphenol intake were evaluated using general linear models accounting for age, state, BMI and energy intake. P values <0·05 (two-tailed) were considered significant. All analyses were conducted using SAS (version 9.3).
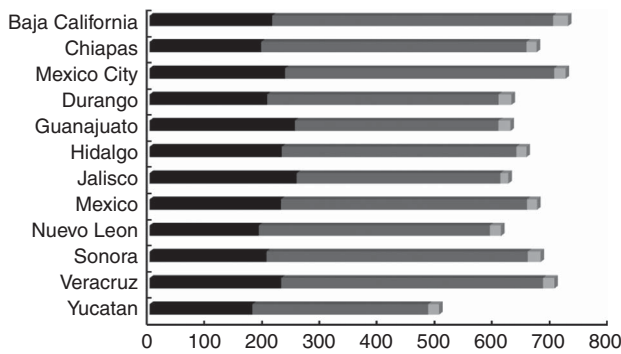
Results

The daily median intakes of total polyphenol, flavonoids, phenolic acids and other polyphenols in adult Mexican women were 694 (25th–75th percentile 413–1103), 235 (25th–75th percentile 141–367), 361 (25th–75th percentile 166–690) and 15·1 (25th–75th percentile 7·9–28·5) mg/d, respectively. Daily intakes of lignans and stilbenes were very low: 0·07 (25th–75th percentile 0·03–0·17) and 0·55 (25th–75th percentile 0·35–0·84) mg/d, respectively. Total polyphenol intake was highest in the states of Baja California (750 mg/d) and Mexico City (746 mg/d) and lowest in Yucatan (536 mg/d) (Fig. 1 and online Supplementary Table S1). Flavonoid and phenolic acid intakes were greatest in Jalisco (270 mg/d) and Chiapas (439 mg/d),

Fig. 1. Geometric mean of the main polyphenol class intakes by state in the Mexican Teachers' Cohort. ■, Flavonoids; ▨, phenolic acids; ▨, other polyphenols.

respectively. Yucatan was the state with the lowest intake of flavonoids (188 mg/d) and phenolic acids (243 mg/d).

The intake of flavonoids, lignans and stilbenes increased with age, whereas the highest consumers of total polyphenols and phenolic acids were those in the 50- to 59-year age group (Table 1). Women living in urban areas consumed more polyphenols, total and all classes, compared with those living in rural areas. Women with BMI <25 kg/m^2 had the highest intake of flavonoids, but the lowest intake of phenolic acids. Current smokers had the highest intake of total polyphenols and phenolic acids, whereas former smokers were the top consumers of flavonoids. The intake of total and all classes of polyphenols increased with the level of physical activity and SES (Table 1).

Phenolic acids were the main contributors to total polyphenol intake (63·5 %), followed by flavonoids (33·5 %) (Table 2). Stilbenes and lignans only accounted for 0·1 % of total polyphenol intake. Regarding polyphenol subclasses, the three most important were hydroxycinnamic acids (61·7 %), flavanols (17·3 %, of which mostly were PA 14·8 %) and flavanones (8·6 %). Other subclasses were less important.

Intake of a total of 287 individual polyphenols could be documented, of which 167 were flavonoids, sixty-seven were phenolic acids, ten were lignans, seven were stilbenes and thirty-six were other polyphenols (Table 2). In all, forty-two polyphenols were consumed in a median quantity of at least 1 mg/d, seventy-seven polyphenols between 0·1 and 1 mg/d, ninety-four polyphenols between 0·01 and 0·1 mg/d and seventy-four polyphenols in amounts between >0 and 0·01 mg/d (online Supplementary Table S2). The most consumed individual

Table 1. Daily intakes of total and polyphenol classes by socio-demographic and lifestyle factors in the Mexican Teachers' Cohort*
(Medians and 25th and 75th percentiles)

Stratification variables	n	Total polyphenols Median	Total polyphenols 25–75th percentile	Flavonoids Median	Flavonoids 25–75th percentile	Phenolic acids Median	Phenolic acids 25–75th percentile	Lignans Median	Lignans 25–75th percentile	Stilbenes Median	Stilbenes 25–75th percentile	Other polyphenols Median	Other polyphenols 25–75th percentile
Age (years)													
20–29	5535	602	371–939	225	135–354	290	145–598	0·53	0·34–0·80	0·07	0·03–0·16	13·8	7·2–28·1
30–39	26 846	655	393–1031	228	139–358	329	158–648	0·54	0·35–0·82	0·07	0·03–0·16	14·5	7·5–28·4
40–49	56 582	708	421–1127	234	140–364	376	171–712	0·55	0·35–0·83	0·07	0·03–0·17	15·3	8·1–28·6
50–59	15 769	752	438–1201	250	148–392	397	174–750	0·57	0·36–0·89	0·08	0·03–0·19	15·7	8·2–28·8
>60	1734	735	445–1184	264	159–412	383	164–714	0·57	0·36–0·89	0·09	0·03–0·20	14·8	7·8–26·8
Area													
Urban	79 161	705	418–1121	239	143–371	367	165–702	0·56	0·36–0·85	0·08	0·03–0·18	15·7	8·2–30·0
Rural	26 046	665	399–1047	223	133–355	344	169–663	0·51	0·32–0·78	0·06	0·02–0·15	13·2	7·0–25·2
BMI (kg/m^2)													
<25	32 495	679	414–1075	246	148–380	334	161–662	0·56	0·36–0·85	0·08	0·03–0·18	14·9	7·8–28·8
25 to <30	40 433	711	425–1122	238	144–371	373	172–703	0·55	0·36–0·84	0·07	0·03–0·17	15·7	8·2–29·6
≥30	23 422	710	416–1139	223	134–348	398	175–731	0·54	0·34–0·82	0·06	0·02–0·16	15·2	8·0–28·1
Smoking status													
Never smoker	79 777	674	409–1055	239	146–371	336	163–658	0·55	0·35–0·84	0·07	0·03–0·16	14·7	7·8–27·9
Former smoker	12 150	795	473–1316	241	146–372	476	197–828	0·58	0·38–0·87	0·12	0·03–0·20	17·9	9·5–33·0
Current smoker	9423	835	483–1486	219	128–344	576	222–1101	0·55	0·36–0·83	0·13	0·03–0·20	17·4	9·3–31·1
Physical activity													
Quartile 1	24 505	634	363–1032	202	117–320	340	150–666	0·47	0·30–0·73	0·05	0·02–0·15	12·8	6·7–24·1
Quartile 2	26 241	685	413–1082	226	137–351	364	169–689	0·52	0·34–0·80	0·07	0·03–0·16	14·7	7·9–27·1
Quartile 3	26 125	715	442–1118	245	154–371	377	179–701	0·57	0·38–0·85	0·08	0·03–0·18	15·9	8·7–29·8
Quartile 4	26 446	776	487–1208	280	178–427	393	188–725	0·65	0·43–0·97	0·09	0·03–0·20	18·2	9·7–38·5
Socio-economic status													
Low	18 259	641	378–1010	216	127–347	326	160–645	0·49	0·31–0·77	0·05	0·02–0·14	12·3	6·4–23·2
Medium	33 474	683	411–1073	235	142–366	352	165–670	0·55	0·35–0·83	0·07	0·03–0·17	14·7	7·9–27·8
High	44 603	748	450–1194	248	153–379	403	177–752	0·58	0·38–0·87	0·09	0·03–0·19	17·6	9·3–33·7

* All P values were <0·001 of differences in median intakes by age, state, energy intake and BMI among stratification variables subgroups.
  Missing values: area, 1259 (1·2 %); BMI, 10 106 (9·5 %); smoking status, 5116 (4·8 %); physical activity, 3149 (3·0 %); socio-economic status, 10 130 (9·5 %).

Table 2. Number of individual polyphenols (PP) and contribution of classes and subclasses of total polyphenols, and the top three most consumed polyphenols for each polyphenol class and subclass in the Mexican Teachers' Cohort

Polyphenol classes and subclasses	% PP class	% total PP	Number of individual PP	Top three most consumed PP	Top three food sources
Total polyphenols	100	100	287	5-Caffeoylquinic acid (19·4 %), 4-caffeoylquinic acid (12·1 %), 3-caffeoylquinic acid (11·4 %)	Caffeinated coffee (28·8 %), decaffeinated coffee (18·6 %), apples (7·2 %)
Flavonoids	100	33·5	167	PA polymers (15·9 %), hesperetin (14·9 %), PA 4-6 monomers (11·4 %)	Apples (18·5 %), oranges and mandarins (13·1 %), orange juice (12·4 %)
Anthocyanins	11·5	3·8	36	Pelargonidin 3-O-glucoside (35·9 %), delphinidin 3-O-glucoside (13·8 %), cyanidin 3-O-glucoside (13·0 %)	Beans (37·3 %), strawberries (26·1 %), fruit-flavoured water (10·6 %)
Chalcones	0·0	0·0	1	Butein (100 %)	Green broad bean (95·8 %), beer (4·2 %)
Dihydrochalcones	0·6	0·2	3	Phloridzin (57·6 %), phloretin 2'-O-xylosyl-glucoside (40·7 %), 3-hydroxyphloretin 2'-O-glucoside (1·7 %)	Apple (98·7 %), pozole (1·0 %), pancita (0·3 %)
Dihydroflavonols	0·0	0·0	4	Dihydromyricetin (90·8 %), dihydromyricetin 3-O-rhamnoside (6·2 %), dihydroquercetin (1·5 %)	Wine (82·3 %), pozole (13·7 %), pancita (4·0 %)
Flavanols	51·6	17·3	20	PA polymers (31·0 %), PA 4–6 monomers (22·1 %), PA 7–10 monomers (14·1 %)	Apples (33·5 %), strawberries (11·4 %), plums (9·4 %)
Flavan-3-ol monomers	7·4	2·5	9	(−)-Epicatechin (49·9 %), (+)-catechin (35·5 %), (+)-gallocatechin (6·3 %)	Apple (19·5 %), prickly pear (14·5 %), green broad bean (13·2 %)
Proanthocyanidins	44·2	14·8	11	PA polymers (31·0 %), PA 4–6 monomers (22·1 %), PA 7–10 monomers (14·1 %)	Apples (35·9 %), strawberries (12·6 %), plums (10·7 %)
Theaflavins	0	0	0		
Flavanones	25·6	8·6	15	Hesperidin (58·5 %), naringin (16·0 %), narirutin (14·1 %)	Orange and mandarin (47·2 %), orange juice (45·6 %), fruit-flavoured water (4·6 %)
Flavones	4·3	1·5	24	Apigenin 6,8-di-C-glucoside (33·3 %), apigenin 6,8-C-galactoside-C-arabinoside (32·4 %), apigenin 6,8-C-arabinoside-C-glucoside (23·8 %)	Orange and mandarin (19·4 %), whole-grain bread (17·6 %), sweet bread (15·4 %)
Flavonols	5·5	1·8	51	Kaempferol 3-O-glucoside (13·3 %), quercetin 3-O-rutinoside (8·0 %), quercetin 3,4'-O-diglucoside (7·8 %)	Beans (22·4 %), Spinach and swiss chards (15·3 %), apples (9·5 %)
Isoflavonoids	0·9	0·3	13	Genistin (22·6 %), daidzin (18·4 %), 6''-O-malonylgenistin (12·6 %)	Soya milk (82·2 %), beans (16·6 %), peanuts (0·6 %)
Phenolic acids	100	63·5	67	5-Caffeoylquinic acid (30·6 %), 4-caffeoylquinic acid (19·0 %), 3-caffeoylquinic acid (18·0 %)	Caffeinated coffee (44·8 %), decaffeinated coffee (29·1 %), corn tortilla (5·8 %)
Hydroxybenzoic acids	2·8	1·8	18	Gallic acid (46·8 %), vanillic acid (22·2 %), 4-hydroxybenzoic acid (10·0 %)	Prickly pear (66·8 %), mamey (6·4 %), walnuts (5·7 %)
Hydroxycinnamic acids	97·2	61·7	47	5-Caffeoylquinic acid (31·5 %), 4-caffeoylquinic acid (19·5 %), 3-caffeoylquinic acid (18·5 %)	Caffeinated coffee (46·1 %), decaffeinated coffee (29·9 %), corn tortilla (5·9 %)
Hydroxyphenylacetic acids	0·0	0·0	2	4-Hydroxyphenylacetic acid (99·9 %), homovanillic acid (0·1 %)	Corn tortilla (45·5 %), beer (16·7 %), atole with milk (9·0 %)
Hydroxyphenylpropanoic acids	0	0	0		
Stilbenes	100	0·0	7	Resveratrol (57·1 %), Resveratrol 3-O-glucoside (14·3 %), Piceatannol 3-O-glucoside (14·3 %)	Wine (45·4 %), strawberries (29·5 %), fruit-flavoured water (12·0 %)
Lignans	100	0·1	10	Lariciresinol (45·5 %), pinoresinol (21·2 %), secoisolariciresinol (18·2 %)	Broccoli and cauliflower (10·8 %), strawberries (9·3 %), fruit-flavoured water (6·1 %)
Other polyphenols class	100	2·9	36	5-Heneicosylresorcinol (21·0 %), 5-heneicosenylresorcinol (16·1 %), 5-nonadecylresorcinol (12·0 %)	Whole-grain breakfast cereals (48·2 %), caffeinated coffee (12·1 %), whole-grain bread (8·9 %)
Alkylmethoxyphenols	9·8	0·3	3	4-Ethylguaiacol (58·1 %), 4-vinylguaiacol (39·9 %), 4-vinylsyringol (2·0 %)	Caffeinated coffee (52·2 %), decaffeinated coffee (45·4 %), margarine (1·9 %)
Alkylphenols	66·0	1·9	13	5-Heneicosylresorcinol (31·9 %), 5-heneicosenylresorcinol (24·4 %), 5-nonadecylresorcinol (18·1 %)	Whole-grain breakfast cereals (73·0 %), whole-grain bread (13·5 %), breakfast cereals (5·1 %)
Tyrosols	0·6	0·0	8	Tyrosol (53·3 %), oleuropein-aglycone (6·7 %), hydroxytyrosol (6·7 %)	Wine (48·1 %), pizza (33·2 %), beer (18·7 %)
Other polyphenols subclass	23·6	0·7	12	Phlorin (48·3 %), pyrogallol (10·7 %), vanillin (9·2 %)	Caffeinated coffee (24·3 %), orange juice (24·2 %), oranges and mandarins (16·0 %)
Cucurminoids	0	0	0		
Furanocoumarins	0·2	0·0	1	Bergapten (100 %)	Orange juice (100 %)
Hydroxybenzaldehydes	2·3	0·1	2	Vanillin (93·2 %), syringaldehyde (6·8 %)	Prickly pear (92·3 %), walnuts (3·4 %), wine (2·3 %)
Hydroxybenzoketones	0	0	0		
Hydroxycinnamaldehydes	0	0	0		
Hydroxycoumarins	0·7	0·0	2	Coumarin (94·7 %), 4-hydroxycoumarin (5·3 %)	Herbal tea (93·3 %), beer (5·7 %), wine (1·0 %)
Hydroxyphenylpropenes	0	0	0		
Methoxyphenols	1·4	0·0	1	Guaiacol (100 %)	Caffeinated coffee (54·5 %), decaffeinated coffee (45·5 %)
Naphtoquinones	1·3	0·0	1	Juglone (100 %)	Walnuts (84·5 %), cakes (7·8 %), tamal (3·9 %)
Phenolic terpenes	0	0	0		
Other polyphenols family	17·7	0·5	5	Phlorin (64·4 %), pyrogallol (14·2 %), catechol (11·3 %)	Orange juice (30·9 %), caffeinated coffee (28·2 %), oranges and mandarins (21·4 %)

PA, proanthocyanidins.
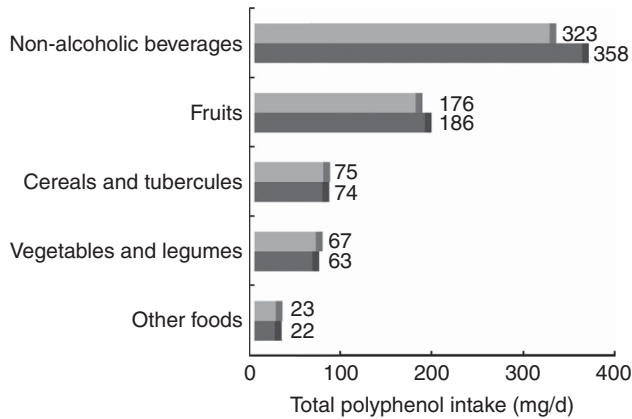
Fig. 2. Median intake of total polyphenols coming from main food groups by area (urban (■) and rural (■)) in the Mexican Teachers' Cohort.

polyphenols were the 5-caffeoylquinic acid (19·4 %), 4-caffeoylquinic acid (12·1 %), 3-caffeoylquinic acid (11·4 %), ferulic acid (8·5 %), PA polymers (5·3 %) and hesperidin (5·0 %). High heterogeneity on the intake of individual polyphenols among individuals was observed – for example, the intake of 5-caffeoylquinic acid ranged from 4·7 to 520 mg/d (5th and 95th percentile of the distribution) (online Supplementary Table S2).

The main food sources of total polyphenols were coffee (47·4 %) and fruit, especially apples (7·2 %), orange and mandarins (5·1 %), and orange juice (4·8 %) (Table 2). After stratifying by state, a great variability in the contribution of food sources was observed. For example, non-alcoholic beverages contributed to total polyphenols between 41 % in Guanajuato and 56 % in Chiapas and Baja California. Fruits contributed from 22 % in Chiapas to 36 % in Jalisco. Cereals and tubercles varied between 6 % in Jalisco and 14 % in Durango. However, the contribution of vegetables and legumes (8–11 %) was similar in all states (online Supplementary Table S3). Intake of total polyphenols coming from non-alcoholic beverages and fruits was higher in urban than rural areas, whereas the opposite was observed for vegetables and legumes (Fig. 2).

Discussion

This is a large study estimating the intake of all known dietary polyphenols, their food sources and their determinants in a large sample of adult women in a Latin-American country. The use of the same FFQ in the entire cohort allowed us to compare differences across states and socio-economic groups. Moreover, the use of Phenol-Explorer[10] allows a straightforward comparison of polyphenol intake with previously published studies, although we need to take into account that some of the differences among studies could be owing to the different comprehensiveness of the dietary questionnaires used. To date, mostly European studies have used this food composition database[7,11–15], and a few recent studies conducted in Sao Paulo-Brazil[16], Korea[27] and Japan[28].

In the present study, the median intake of total polyphenols was 694 mg/d, ranging from Yucatan (536 mg/d) to Baja California and Mexico City (approximately 750 mg/d). Therefore, no large differences were observed between Mexican states.

Dietary patterns derived in this cohort show three distinct diets, one rich in vegetables, fruit and legumes; a Western-like diet rich in processed meats, fast foods and red meat; and a Modern Mexican diet rich in tortillas, hot peppers and sodas[29]. Patterns differ between regions in the country; the Western pattern was more frequently consumed in the northern regions of the country, and the Fruit and Vegetables and the Modern Mexican patterns were more frequently consumed in the southern regions. In our study, polyphenol intake was almost 2·5-fold the median intake in Sao Paulo-Brazil (300 mg/d)[16]. However, it was comparable with the mean intake in some Mediterranean countries, similar to that observed in the European Prospective Investigation into Cancer and Nutrition (EPIC)-Greece (584 mg/d)[7] and Spain (280 and 820 mg/d in institutionalised elderly women and subjects at high risk of cardiovascular diseases, respectively)[12,14]. However, total polyphenol mean intake in other European regions was much higher, as observed in French women participating in the Supplémentation en Vitamines et Minéraux Antioxydants study (1108 mg/d)[11], UK women in the EPIC study (1603 mg/d)[7] and Polish women in the Health, Alcohol and Psychosocial factors In Eastern Europe (HAPPIE) study (1727 mg/d)[13]. A large south-to-north gradient was observed in Europe, where the intake in EPIC-Aarhus (Denmark) (1626 mg/d) tripled the consumption in EPIC-Greece[7]. These large differences in polyphenol intake were because of the high consumption of tea in the UK and coffee in northern Italy and northern European countries. In Mexico, tea is not commonly consumed and coffee consumption is lower than in Europe, although it is still the main dietary source of total polyphenols in our study (>50 %), like in Brazil (70 %)[16].

In the Mexican states with the highest intake of polyphenols, the median intake of phenolic acids was between 350 and 440 mg/d, being the main contributors to total polyphenol intake (approximately 65 %), whereas in the states with a lower polyphenol intake (such as Guanajuato and Jalisco), phenolic acid median intake was below 300 mg/d, accounting only for 55 % of total polyphenols. In Brazil, although the total polyphenol intake was lower (mean = 285 mg/d) than in our study, phenolic acids contributed to 75 % of total polyphenol intake[16]. In Europe, phenolic acid intakes were higher, approximately 500 and 700 mg/d in Mediterranean and non-Mediterranean countries, respectively, and they contributed to 47 and 57 % of total polyphenols, respectively[7]. Despite these differences in total phenolic acid intake, in all cases, coffee was the main food source of phenolic acids either in Mexico (approximately 75 %), Europe (70–75 %)[30] or Brazil (>90 %)[16]. In Mexico, median coffee intake was between 38 and 55 ml/d and in Europe the median varied between 90 mL/d of mainly espresso in Italy and 900 ml/d of mostly filtered diluted coffee in Denmark[30], whereas in Brazil the mean intake was 168 ml/d[16]. Espresso coffee is a concentrated coffee, and thus it is approximately 2-fold richer in polyphenols than normal filtered coffee, and 4-fold richer than 'American' or filtered diluted coffee[31], which is the habitual coffee of Mexicans.

The daily intake of flavonoids in Mexico was between 188 (Yucatan) and 270 mg/d (Jalisco). In Guanajuato and Jalisco, flavonoids contributed about 40 % of total polyphenols, whereas in the rest of the states they only accounted for

approximately 30 %. In Brazil, flavonoids only account for 15 % of total polyphenol intake[16]. This low figure could be because of the low consumption of fruits and vegetables in this population (mean = 67 g/d) or a methodological error. In Europe, flavonoid intake was also higher than in Mexico (approximately 500 mg/d), accounting for ~40 % of total polyphenols[7]. This was even higher in the UK (900 mg/d) owing to the large consumption of tea, the main dietary source of flavonoids in this country[7,15]. The low intake of flavonoids in Mexican women and Brazilians[16] may be because of the almost null tea consumption and the potential underestimation of flavonoid intake, because the food composition data of several tropical foods (such as prickly pears, nopal, squash blossoms, mamey, zapote, guava, jicama) are not available or not fully described in Phenol-Explorer[10]. Among the flavonoid subclasses, PA and flavanones were the most consumed ones, with fruit and fruit juices as their major dietary sources. Our results cannot be compared directly with other descriptive studies on flavonoids[18,32,33] using USDA databases[19], as intake values in these studies were calculated and reported as aglycones, and not as glycosides and esters as done here[8]. If we convert our results to aglycone equivalents, the median intake of total flavonoids (sum of flavonoid monomers and PA) in Mexico is 140 mg/d, which is lower than in Europe (mean 370 mg/d)[32] and the USA (mean 285 mg/d)[33,34].

The median intakes of stilbenes, lignans and other minor classes of polyphenols were very minor: 0·1, 0·6 and 15·1 mg/d, respectively. The largest contributors were alkylphenols (alkylresorcinols (median = 5·7 mg/d)) mainly found in wholegrain cereals. In women from non-Mediterranean countries, the consumption of alkylresorcinols was higher (30 mg/d) than in Mexican women, because they consume larger amounts of whole-grain cereals. Stilbenes and tyrosols are characteristic of wine and olives/olive oil, respectively. Those foods are less consumed in Mexico and Brazil[16], and thus stilbenes (0·1 mg/d) and tyrosols (0·1 mg/d in Mexico and 3·1 mg/d in Brazil) were minor polyphenol subclasses. However, in women from Mediterranean countries, the mean intake of stilbenes and tyrosols was higher (1·2 and 22·5 mg/d, respectively) owing to the greater consumption of wine, olive oil and olives[7].

Associations between polyphenol intake and lifestyle factors have been examined in several studies. Physically active women with higher SES had a larger consumption of total polyphenols, flavonoids and phenolic acids as in the EPIC study[7]. However, women with a BMI ≥30 kg/m² had a higher intake of total polyphenols and phenolic acids, because of a higher consumption of coffee. Current smokers also consumed more total polyphenols and phenolic acids, as smokers are much more likely to drink coffee[35]. Despite this, both current smokers and women with BMI ≥30 kg/m² tended to consume less flavonoids mainly provided from fruit and fruit juices. A similar pattern was described in both the EPIC and the Polish arm of the HAPPIE study[7,13].

Polyphenol intake was compared in urban and rural areas. Mexican women living in urban areas had a higher intake of total and all classes of polyphenols compared with those living in rural areas. These results were expected for phenolic acids, because coffee was more consumed in urban areas and especially for women with a higher SES, who tended to live in urban areas. Flavonoid intake was also higher in urban areas; it is probably owing to the better access to fruit and vegetables in urban than rural areas[36]. Another potential explanation could be that women in rural areas consume more local fruits and vegetables with limited or no polyphenol composition data in Phenol-Explorer, resulting in an underestimation of polyphenol intake in women living in rural areas.

In the present study using an FFQ, 287 individual polyphenols were described, whereas intakes of 347, 337 and 290 polyphenols have been reported in the Polish arm of the HAPIEE study[13], in the SU.VI.MAX study[11] and in the Spanish PREvención con DIeta MEDiterránea study[12], respectively. In the studies using a single 24-h dietary recall, the number of individual polyphenols was higher, especially in the EPIC study (n 437)[7], but comparable to the Brazilian study (n 317)[16]. In our study, only forty-two individual polyphenols were found to be consumed in a median amount >1 mg/d; however, approximately 100 polyphenols were consumed in a mean quantity of at least 1 mg/d on average in the remaining studies[7,11–13]. This phenomenon is due to the highly skewed distribution of polyphenol intakes.

A large inter-individual variability in the intake of individual polyphenols was observed (up to 100-fold change) – for example, the median intake of 5-caffeoylquinic acid was 90 mg/d, ranging from 4·7 to 520 mg/d (5th and 95th percentile of the distribution). High heterogeneity among subjects is also described in other studies[7,11–13,16]. In EPIC, the intake of 5-caffeoylquinic acid varied between 20 and 460 mg/d (5 and 95 %, median 195 mg/d)[7]. Furthermore, the most consumed individual polyphenols were the 5-, 4- and 3-caffeoylquinic acids, and ferulic acid, which are almost exclusively related to coffee. PA and hesperidin were also abundant individual polyphenols such as in the European studies[7,11–13].

The first strength of this study was the large number of participants in the MTC study. The second was the use of an extensive food composition database, Phenol-Explorer, including a complete list of 500 polyphenols expressed as they are found in foods and including individual retention factors[10,26]. The third advantage was the use of a validated FFQ in the whole cohort[24]. However, our study has also some limitations. A relevant weakness is the likely underestimation of true polyphenol intake, owing to missing food composition data on some tropical foods in the FFQ. Our results cannot be totally generalisable, as all participants were teachers and therefore no illiterate people or women with very low education were recruited.

In conclusion, these data indicate a large heterogeneity in intakes of individual polyphenols among Mexican women, but a moderate heterogeneity across Mexican states. The main food sources per individual polyphenol were similar among states. In addition, we showed that socio-demographic, anthropometric and lifestyle factors are associated with different levels of polyphenol intake. Indeed, women living in urban areas consumed more polyphenols, total and all classes, compared with those living in rural areas. These descriptive data provide a platform to further investigate the role of polyphenol intake against disease outcomes.

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Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114518001381

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