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ORIGINAL CONTRIBUTION

Estimated dietary intake of polyphenols in European adolescents: the HELENA study

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Abstract

Purpose Knowledge about polyphenols intakes and their determinants among adolescents might be helpful for planning targeted prevention strategies at an early age.

Methods In the European multicenter cross-sectional HELENA study of 2006–2007, 2428 subjects (47% boys) had data on dietary intake of polyphenols from 2 non-consecutive 24 h recalls via linking with the Phenol-Explorer database. Differences by sex, age, country, BMI, maternal education, paternal education, family affluence, smoking status, alcohol use, and physical activity were explored by linear regression.

Results Median, lower and upper quartiles of polyphenol intakes were 326, 167 and 564 mg/day, respectively. Polyphenol intake was significantly higher in the oldest (16–17.49 years), girls, non-Mediterranean countries, lowest BMI, highest paternal education, and alcohol consumers. Main food contributors were fruit (23%, mainly apple and pear, i.e., 16.3%); chocolate products (19.2%); and fruit and vegetable juices (15.6%). Main polyphenol classes were flavonoids (75–76% of total) and phenolic acids (17–19% of total). The three most consumed polyphenols were proanthocyanidin polymers (> 10 mers), hesperidin, and proanthocyanidin 4–6 oligomers.

Conclusion The current study provided for the first time numbers on the total polyphenol intake and their main food sources in a heterogeneous group of European adolescents. Major differences with adult populations are the lower polyphenol consumption and the major food sources, such as chocolate and biscuits. The discussed determinants and polyphenol types already point to some important population groups that need to be targeted in future public health initiatives.

Keywords Polyphenol · Consumption · Food contributors · HELENA · Determinants · Mediterranean

Introduction

Polyphenols are bioactive compounds which are widely distributed in plant-based foods such as vegetables, fruit, cocoa, tea, coffee and wine [1]. Polyphenols represent a very diverse group of compounds with over 500 different molecules identified in foods, which can be divided into four main classes, according to their chemical structure: flavonoids, phenolic acids, stilbenes and lignans [2]. The chemical structure affects the polyphenol absorption in the gut, bioavailability and possibly their health effects [3]. Over the last 20 years, there has been great interest in the potential health benefits of polyphenols, such as antioxidant, anti-inflammatory and anti-carcinogenic effects [4]. A literature review has shown an inverse association between polyphenol intake and risk of hypertension among 2725 Polish adults during a 2–4 years follow up study [5]; a positive association with HDL level in 500 Italian adults [6], and a reduced risk for type 2 diabetes in 3400 elderly at high risk for cardiovascular disease [7]. Although current evidence did not show any classical deficiencies due to low polyphenol intakes, recently they have been discussed as 'lifespan essentials'

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as they are needed throughout the full lifespan to reduce the risk of a range of chronic diseases [8, 9].

Some descriptive data on the intake of polyphenols is already available on population-level. A recent study identified the mean dietary intake of polyphenols as 377 (s.e. 15) mg/day among adults and elderly in Sao Paulo. Higher mean dietary intake of polyphenols was found among men, who were white, in normal weight, and in the higher physical activity groups [10]. A study of people with type 2 diabetes in Italy reported that the mean total polyphenol intake was 683 ± 6 mg/day and polyphenol intake increased with age and education level and decreased with BMI [11]. Another study from Europe revealed that mean total polyphenol intake among adults was the highest in Aarhus-Denmark (1786 mg/day in men and 1626 mg/day in women) and the lowest in Greece (744 mg/day in men and 584 mg/day in women) [12]. In all three studies, coffee was the most important food source of total polyphenols. However, there is no descriptive total polyphenol intake study available in adolescents, although a few studies exist on specific polyphenols in single-country studies [13–15]. Adolescence is a critical period that can affect adult chronic diseases, so dietary intake during adolescence may indicate adult lifestyle and health [16]. For this reason, the identification of the intake of polyphenols among adolescents is important and might be helpful for interventions in promoting healthy eating behavior and preventing dietary-related chronic diseases.

Therefore, the purpose of the present study is to estimate European adolescent's dietary intake of polyphenols, the main food contributions and socio-demographic differences using the Phenol-Explorer database as the most complete polyphenol database currently published [17]. The "Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study" (HELENA-CSS) study provides the opportunity to explore polyphenol intake among European adolescents by detailed dietary recall data.

Materials and methods

Study population

The HELENA study is a multicenter study on lifestyle and nutrition among adolescents from 10 European cities: Athens and Heraklion (Greece), Dortmund (Germany), Ghent (Belgium), Lille (France), Pecs (Hungary), Rome (Italy), Stockholm (Sweden), Vienna (Austria), and Zaragoza (Spain). The survey was conducted from October 2006 to December 2007, in 3528 adolescents aged 12.5–17.5 years, randomized and stratified by geographical location, age and socio-economic status. Details on specific methods have been reported elsewhere [18, 19]. The participants and their parents provided written informed consent and the study protocol was approved by the ethics committee of each city involved [20].

Data on food intake from Heraklion and Pecs were not available (i.e., two 24-h dietary recalls and a FFQ) for the present analysis. Furthermore only 2428 adolescents from 8 European cities, who had also completed two non-consecutive 24-h dietary recalls were included in the present analysis.

Dietary, socio-demographic and lifestyle information

Dietary data were retrieved from a 24-h recall on 2 non-consecutive days, within a time-span of 2 weeks, but not on Fridays and Saturdays, using HELENA-Dietary Assessment Tool (DIAT). HELENA-DIAT consists of six meal occasions and adolescents were invited to select all food items from a standardized menu structure. Quantitatively detailed information was collected using household measurements or pictures of portion sizes for each selected item [21, 22]. Foods reported in the 24-h recalls were linked to the German Food Code and Nutrient Data Base (Bundeslebensmittelschlüssel, BLS, version II.3.1) [23] to assess energy and nutrient intakes.

Collected demographic data included information on sex, age, city and socio-economic status which was examined by parental education and by the Family Affluence Scale (FAS). Parental education level of mother and father were reported using the International Standard Classification of Education (ISCED) classification [24] as "lower education", "higher secondary education" and "university education". A refitted version of the FAS [24] was used as an indicator of the adolescent's material conditions in family. FAS was scored from 0 to 4 (low FAS score) and 5–8 (high FAS score) based on adolescents' report on internet availability at home (0 no, 1 yes), family car ownership (0–3 depending on amount), computer ownership (0–3 depending on amount) and having one's own bedroom (0 no, 1 yes). Based on questionnaire data, smoking status, alcohol status and physical activity (hours/week) were computed. Weight status was classified following the International Obesity Task Force [25] based on measured weight and height. The cities (Athens in Greece, Roma in Italy, and Zaragoza in Spain) were considered as Mediterranean (MED), while Dortmund in Germany, Ghent in Belgium, Lille in France, Stockholm in Sweden, and Vienna in Austria were considered as non-MED.

Estimation of polyphenol intake

Data on the polyphenol content in food were assessed using the Phenol-Explorer database (http://www.phenol-explorer.eu) [26], which contains four main polyphenol classes: flavonoids, phenolic acids, stilbenes, lignans and a number of minor polyphenols (described as "other polyphenols" in this manuscript) like tyrosols, alkylphenols (mainly alkylresorcinols), and alkylmethoxyphenols [12, 27]. Polyphenol content values described in the Phenol-Explorer database are obtained by different analytical methods. For most compounds, data used for this work were obtained by 'chromatography', except for lignans and for phenolic acids in some specific foods (cereals, walnuts, olives and legumes) that were measured by 'chromatography after hydrolysis'. Some foods that could contain polyphenols that were present in HELENA-DIAT, but not in the Phenol-Explorer database, such as margarine, palm oil, and coconut milk were excluded from the database. Complex foods were calculated according to their ingredients in the recipes. Some processed foods are already food entries in the Phenol-Explorer database, such as tea infusion and fruit juices so no additional retention factors were needed for those processed foods. Processed foods, which are not in the Phenol-Explorer database, such as canned foods and pre-packaged meals were estimated based on the percentages of ingredients. Vegetable oil was estimated as the combination of sunflower oils, corn oils, and soy oils. Composition of coffee, herbal tea and olive oil was calculated based on common brands in the country of study. Individual polyphenol intake was calculated by multiplying individual polyphenols content in each food item by the daily consumption of each food. Total polyphenol intake was estimated as the sum of intakes of the individual polyphenols.

Statistical analyses

Data were presented as means, standard errors, percentages, medians and the 25th and 75th percentiles, as appropriate. The dietary polyphenol intakes were described as absolute intake (mg/day), whereas the contribution of each polyphenol class and subclass to the total polyphenol intake was reported as percentage of total polyphenol intake. Median and the 25th and 75th percentiles were used as measures of central tendency and variability of total polyphenol intake. The general linear models were used to compare differences in polyphenol intakes by sex, age, European region, BMI, maternal education, paternal education, FAS, smoking status, alcohol use, and physical activity. Using energy-adjusted polyphenol intake in testing determinants of polyphenol intake retrieved similar results (data not shown). Regression adjustment for sex, age, European region, energy intake, and month of 24-h recall was performed. Square root-transformation of polyphenol intakes was performed to fit normality when required. Differences in daily consumption of food groups were tested by Mann–Whitney *U* test. Reported *P* value < 0.05 (two-tailed) was considered significant. Analyses were processed using Statistical Package for Social Science (SPSS, version 23).

Results

Overall polyphenol intake

Mean, median, lower quartile and upper quartile of polyphenol intakes for the whole population were 329 (adjusted for sex, age European region, energy intake and month of 24-h recall), 326, 167 and 564 mg/day, respectively. The 5th and 95th percentiles were 42 and 1163 mg/day, respectively (Supplemental Fig. 1). Mean energy-adjusted polyphenol intake was 160 mg/day/1000 kcal. The highest total polyphenol intake was in Ghent (in boys 588 mg/day) and in Vienna (in girls 508 mg/day), whereas the lowest intake in both sexes was in Zaragoza (in boys 212 mg/day and in girls 203 mg/day) (Fig. 1).

Socio-demographic and lifestyle determinants

The mean intakes of total polyphenols and polyphenol classes are shown according to socio-demographic and lifestyle characteristics in Table 1. Total polyphenol intake was depending on age, sex, European region, BMI, maternal education, paternal education, FAS, smoking status and alcohol intake. The intake of total polyphenols and flavonoids was higher in girls than in boys. Increases by age (independent of energy intake) were seen for total polyphenols, phenolic acids and other polyphenols. Non-MED countries (457 mg/day) had a higher intake of total polyphenols than MED countries (275 mg/day), due to higher flavonoid and phenolic acid intake, but the intake of lignans and stilbenes were higher in MED countries than non-MED countries. Adolescents with underweight, a higher parental education, low FAS score or who drank alcohol showed the highest intakes of total polyphenols, mainly due to higher flavonoid intake.

Food group contributions

Daily consumption of food groups is presented in Table 2 to compare food intakes between MED countries and non-MED countries. Many food groups were significantly different, except stalk vegetables, sprout, stone fruits, dairy products, sugar, honey, jam and syrup, other non-alcoholic beverages, wine, and soy products. The contribution of food groups to total polyphenols and each polyphenol class is shown in Table 3. In MED and non-MED countries, the main dietary sources for total polyphenols were fruit (24 and 22%, respectively), chocolate products (21 and 19%, respectively); fruit and vegetable juices (18 and 15%, respectively). In the fruit group, apple/pear was the largest contributor to total polyphenol intake (14–17%). Other important contributors were cereal products, cakes/biscuits and coffee/tea (tea

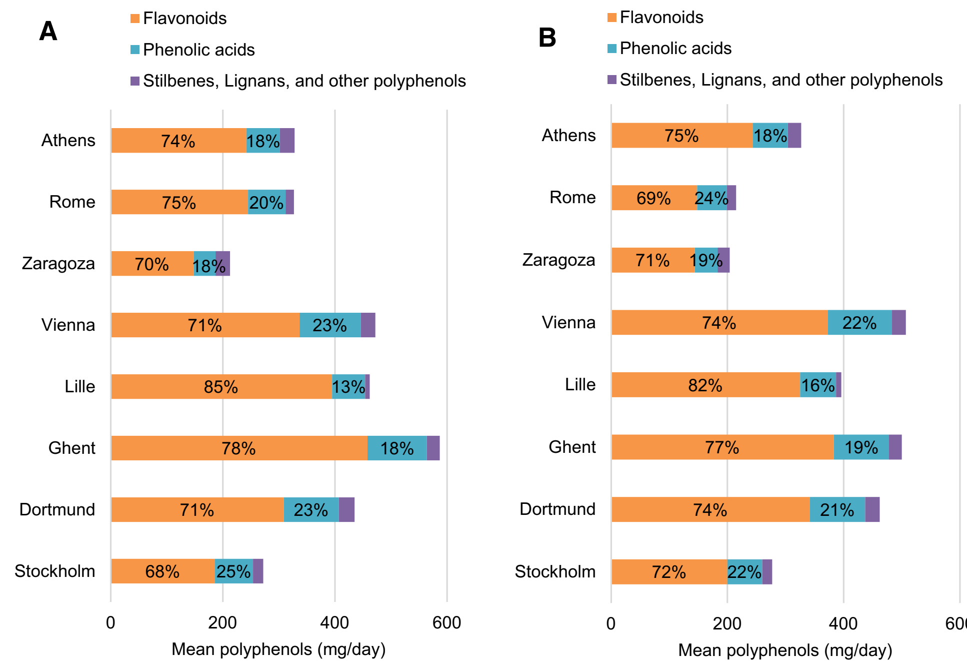

Fig. 1 Daily mean polyphenol intake (mg/day) and percentage contribution, stratified by sex (**a** boys; **b** girls) and center, adjusted for age, energy intake and month of 24-h recall

was a larger contributor in non-MED while coffee in the MED countries). For flavonoids, all trends were the same. Coffee was the primary food source to phenolic acids intake in both MED countries (26%) and non-MED countries (29%). The major food sources of lignans were bread, crisp bread, rusks and crackers in all European regions (58–71%). Wine was the main source of stilbenes in all regions, with a contribution of 51–57%. Cereal products were the most important dietary source of other polyphenols, especially alkylphenols in all regions (54–80%).

Polyphenol classes and subclasses

Table 4 shows the contribution of classes and subclasses to total polyphenol intake. The main polyphenol classes were flavonoids (75–76% of total intake of polyphenols) and phenolic acids (17–19% of total intake of polyphenols) in all sexes, in both MED countries and non-MED countries. Stilbenes and lignans contributed < 1% of total polyphenol intake with mean intakes ranging from 0.03 to 0.04 mg/day and 0.6 to 1 mg/day, respectively, in all regions. The top three main contributors of polyphenol subclasses were flavanols (ranging from 48% in girls from MED countries to 54% in girls from non-MED countries), flavanones (ranging from 16% in girls from non-MED countries to 21% in boys from MED countries) and hydroxycinnamic acids (ranging from 16% in boys from MED countries to 17% in boys from non-MED countries), whereas alkylphenols, flavones, and flavonols accounted for 1–3% of total polyphenol intake. Other subclasses had lower proportions (< 1%).

Individual polyphenols

Of the 384 consumed individual polyphenols in the HELENA study, 20 had a mean intake higher than 1 mg/day, 58 between 0.1 and 1, 90 between 0.01 and 0.1 mg/day, and 216 polyphenols between > 0 and 0.01 mg/day (Supplemental Table 1). The mean intake of the 25 most consumed individual polyphenols and their three main food sources are shown in Table 5. The three most consumed polyphenols in both sexes from all regions were proanthocyanidin polymers (> 10 mers), hesperidin, and proanthocyanidin 4–6 oligomers which were consumed in quantities above 28 mg/day. Their main food sources were chocolate products, fruit and vegetable juices, apples, and pears. Coffee was the main contributor to the intake of 4-caffeoylquinic acid (88.1%) and 3-caffeoylquinic acid (78.7%), whereas tea was the main food source of gallic acid (57.5%) and procyanidin dimer B1 (38.9%). A comparison between MED countries and non-MED countries was made for the top 10 most consumed individual polyphenols in Fig. 2: all of them were higher in non-MED countries than MED countries.

Discussion

To our knowledge, this study is the first to describe a detailed intake of total polyphenols, their major food group and individual food sources in adolescents from different European countries. The influence of socio-demographic and lifestyle characteristics was also identified. Most previous studies were not focused on adolescence [12, 17, 28–31] and used a

Table 1 Adjusted mean intake of total and polyphenol classes according to socio-demographic and lifestyle factors in the HELENA study

Characteristics	*N*	Polyphenols (mg/day)			Flavonoids (mg/day)			Phenolic acids (mg/day)		
		Mean	s.e.	*P* value	Mean	s.e.	*P* value	Mean	s.e.	*P* value
Sex				< 0.001			< 0.001			0.072
Boys	1139	333	0.1		240	0.1		81	0.0	
Girls	1289	389	0.1		284	0.1		88	0.0	
Age group (years)				0.016			0.518			< 0.001
12.5–13.99	770	346	0.1		267	0.1		75	0.1	
14–14.99	607	345	0.2		256	0.1		75	0.1	
15–15.99	563	356	0.2		253	0.1		85	0.1	
16–17.49	488	396	0.2		271	0.1		104	0.1	
European region				< 0.001			< 0.001			< 0.001
Mediterranean countries	915	275	0.1		202	0.1		65	0.1	
Non-Mediterranean countries	1513	457	0.1		329	0.1		106	0.0	
Body mass index (kg/m^2)				0.025			0.033			0.038
Underweight	161	397	0.4		299	0.3		85	0.2	
Normal	1755	357	0.1		262	0.0		77	0.0	
Overweight	392	322	0.2		235	0.1		75	0.1	
Obesity	120	372	0.5		252	0.4		101	0.2	
Education of mother				0.014			0.173			0.051
Lower (secondary) education	803	332	0.1		247	0.1		77	0.1	
Higher secondary education	740	375	0.1		268	0.1		89	0.1	
Higher education or university degree	885	375	0.2		271	0.1		87	0.1	
Education of father				0.046			0.038			0.335
Lower (secondary) education	889	337	0.1		242	0.1		80	0.1	
Higher secondary education	649	369	0.1		271	0.1		86	0.1	
Higher education or university degree	890	376	0.2		272	0.1		87	0.1	
Family affluence scale (FAS)				0.036			0.012			0.925
Low-FAS score (0–4)	1061	374	0.1		274	0.1		85	0.0	
High-FAS score (5–8)	1367	347	0.1		248	0.1		84	0.0	
Smoking status				0.053			0.002			0.02
Never	1501	380	0.1		285	0.1		77	0.0	
Former smoker	494	356	0.2		257	0.2		84	0.1	
Current smoker	433	345	0.2		241	0.2		92	0.1	
Alcohol use				< 0.001			0.025			< 0.001

Table 1 (continued)

Characteristics	N	Polyphenols (mg/day)			Flavonoids (mg/day)			Phenolic acids (mg/day)		
		Mean	s.e.	P value	Mean	s.e.	P value	Mean	s.e.	P value
No	1862	330	0.1		248	0.1		72	0.0	
Yes	566	392	0.2		274	0.1		98	0.1	
Physical activity				0.083			0.258			0.41
< 60 min/day	856	347	0.1		249	0.1		83	0.1	
≥ 60 min/day	1393	369	0.1		261	0.1		86	0.0	
Characteristics	N	Lignans (mg/day)			Stilbenes (mg/day)			Other polyphenols (mg/day)		
		Mean	s.e	P value	Mean	s.e	P value	Mean	s.e	P value
Sex				0.622			0.437			0.569
Boys	1139	1.0	0.0		0.051	0.0		21	0.0	
Girls	1289	1.1	0.0		0.045	0.0		22	0.0	
Age group (years)				0.873			0.206			0.004
12.5–13.99	770	1.0	0.0		0.038	0.0		20	0.0	
14–14.99	607	1.0	0.0		0.048	0.0		19	0.0	
15–15.99	563	1.1	0.0		0.046	0.0		21	0.0	
16–17.49	488	1.1	0.0		0.060	0.0		25	0.0	
European region				0.001			0.011			0.562
Mediterranean countries	915	1.2	0.0		0.059	0.0		21	0.0	
Non-Mediterranean countries	1513	0.9	0.0		0.038	0.0		22	0.0	
Body mass index (kg/m^2)				0.207			0.785			0.856
Underweight	161	1.0	0.0		0.051	0.0		21	0.0	
Normal	1755	0.9	0.0		0.044	0.0		21	0.0	
Overweight	392	1.0	0.0		0.040	0.0		21	0.0	
Obesity	120	1.3	0.0		0.057	0.0		23	0.1	
Education of mother				0.688			0.821			0.058
Lower (secondary) education	803	1.0	0.0		0.052	0.0		20	0.0	
Higher secondary education	740	1.1	0.0		0.046	0.0		22	0.0	
Higher education or university degree	885	1.1	0.0		0.045	0.0		22	0.0	
Education of father				0.147			0.642			0.667
Lower (secondary) education	889	0.9	0.0		0.045	0.0		22	0.0	
Higher secondary education	649	1.0	0.0		0.045	0.0		21	0.0	
Higher education or university degree	890	1.1	0.0		0.053	0.0		22	0.0	

Table 1 (continued)

Characteristics	*N*	Lignans (mg/day)			Stilbenes (mg/day)			Other polyphenols (mg/day)		
		Mean	s.e	*P* value	Mean	s.e	*P* value	Mean	s.e	*P* value
Family affluence scale (FAS)				0.006			0.053			0.539
Low-FAS score (0–4)	1061	1.1	0.0		0.041	0.0		21	0.0	
High-FAS score (5–8)	1367	0.9	0.0		0.055	0.0		22	0.0	
Smoking status				0.716			0.005			0.102
Never	1501	1.1	0.0		0.035	0.0		21	0.0	
Former smoker	494	1.0	0.0		0.045	0.0		23	0.0	
Current smoker	433	1.0	0.0		0.066	0.0		20	0.0	
Alcohol use				<0.001			<0.001			<0.001
No	1862	0.8	0.0		0.032	0.0		17	0.0	
Yes	566	1.3	0.0		0.067	0.0		26	0.0	
Physical activity				0.17			0.036			0.067
<60 min/day	856	1.0	0.0		0.036	0.0		21	0.0	
≥ 60 min/day	1393	1.1	0.0		0.049	0.0		23	0.0	

P value is for differences in mean

Means and standard error (s.e.) were calculated using general linear model adjusted for sex, age, European region, body mass index, parental education, FAS, smoking status, alcohol use, energy intake and month of 24-h recall

Table 2 Daily consumption of food groups in the HELENA (Healthy Lifestyle in Europe by Nutrition in Adolescents) Study

Food items	g/ml FEM/person/day									P value*
	All			MED countries			Non-MED countries			
	Median	p25	p75	Median	p25	p75	Median	p25	p75	
Potatoes and other tubers	60	0	180	0	0	115	90	0	210	< 0.001
Vegetables	164	51	350	210	66	409	146	44	317	< 0.001
Leafy vegetables	0	0	4	0	0	28	0	0	0	< 0.001
Fruiting vegetables	26	0	113	38	0	140	16	0	101	< 0.001
Root vegetables	0	0	0	0	0	0	0	0	0	< 0.001
Cabbages	0	0	0	0	0	0	0	0	0	< 0.001
Grain and pod vegetables	0	0	0	0	0	0	0	0	0	< 0.001
Onion, garlic	0	0	0	0	0	0	0	0	0	< 0.001
Stalk vegetables, sprout	0	0	0	0	0	0	0	0	0	0.397
Mixed salad, mixed vegetables	0	0	80	0	0	52	0	0	90	< 0.001
Legumes	0	0	0	0	0	0	0	0	0	< 0.001
Fruit	150	0	340	130	0	300	175	0	370	< 0.001
Citrus fruit	0	0	0	0	0	70	0	0	0	< 0.001
Apple and pear	0	0	140	0	0	100	0	0	185	< 0.001
Grape	0	0	0	0	0	0	0	0	0	0.001
Stone fruits	0	0	0	0	0	0	0	0	0	0.593
Berries	0	0	0	0	0	0	0	0	0	0.015
Other fruits	0	0	106	0	0	100	0	0	125	0.004
Olives	0	0	0	0	0	0	0	0	0	< 0.001
Nuts	0	0	0	0	0	0	0	0	0	0.008
Seeds	0	0	0	0	0	0	0	0	0	< 0.001
Dairy products	403	188	726	440	225	675	380	150	769	0.076
Cereal products	350	209	540	319	160	521	367	231	550	< 0.001
Flour, flakes, starches, semolina and pastry	0	0	0	0	0	4	0	0	0	< 0.001
Pasta, rice, other grains	120	0	263	112	0	240	120	0	270	0.013
Bread, crispbread, rusks and crackers	158	73	270	120	58	250	180	93	276	< 0.001
Breakfast cereals	0	0	24	0	0	15	0	0	30	0.001
Cakes, biscuits, and sweets	144	60	285	129	54	247	155	60	308	< 0.001
Cakes and biscuits	56	0	150	75	0	160	41	0	140	< 0.001
Chocolate products	10	0	57	10	0	35	15	0	70	< 0.001
Confectionary non-chocolate, candied fruits	0	0	10	0	0	3	0	0	15	< 0.001
Savoury snack	0	0	0	0	0	0	0	0	4	< 0.001
Ice cream, water ice	0	0	0	0	0	0	0	0	0	0.002
Sugar, honey, jam and syrup	0	0	12	0	0	12	0	0	15	0.055
Meat, fish and eggs	292	160	465	340	182	565	269	147	420	< 0.001
Fats and oils	19	0	44	25	8	51	13	0	40	< 0.001
Vegetable oils	5	0	28	22	6	47	0	0	12	< 0.001
Butter and animal fats	0	0	12	0	0	0	3	0	22	< 0.001
Non-alcoholic beverages	650	250	1290	350	150	750	880	400	1635	< 0.001
Fruit and vegetable juices	200	0	400	25	0	330	200	0	500	< 0.001
Carbonated/soft/isotonic drinks	250	0	750	0	0	400	400	0	1000	< 0.001
Coffee	0	0	0	0	0	0	0	0	0	0.037
Tea	0	0	0	0	0	0	0	0	0	< 0.001
Herbal tea	0	0	0	0	0	0	0	0	0	0.045
Other non-alcoholic beverages	0	0	0	0	0	0	0	0	0	0.115
Alcoholic beverages	0	0	0	0	0	0	0	0	0	0.004
Wine	0	0	0	0	0	0	0	0	0	0.176

Table 2 (continued)

Food items	g/ml FEM/person/day									*P* value*
	All			MED countries			Non-MED countries			
	Median	p25	p75	Median	p25	p75	Median	p25	p75	
Beer, cider	0	0	0	0	0	0	0	0	0	< 0.001
Spirits and cocktails	0	0	0	0	0	0	0	0	0	0.002
Condiments, spices, and sauces	31	0	90	12	0	64	44	0	100	< 0.001
Soy products	0	0	0	0	0	0	0	0	0	0.162
Other products	0	0	0	0	0	0	0	0	0	< 0.001

FEM fresh edible mass, *MED countries* Mediterranean countries, *p25* percentile 25, *p75* percentile 75

*Comparisons between MED countries and non-MED countries were performed by Mann–Whitney *U* test

large heterogeneity of food consumption data, so the comparisons of polyphenol intake with other published population groups is difficult. Therefore, the use of a similar methodology for polyphenol assessment can facilitate a comparison of polyphenol intake in different studies [32, 33].

Overall polyphenol intake

Reported polyphenol intake levels in literature were 1193 ± 510 mg/day in the French SU.VI.MAX [17], 820 ± 323 mg/day in a Spanish population at high cardiovascular risk [30], 1757 ± 696 mg/day in the Polish arm of the HAPIEE study [28], 989 ± 360 mg/day in Polish adults [31], 377.5 mg/day in Sao Paulo [10] and 1177 mg/day in men and 1192 mg/day in women from the European EPIC study [12]. Polyphenols intake adjusted by energy intake was also reported in previous studies, with a mean value of 377 ± 3.2 mg/1000 kcal/day in the TOSCA.IT Study [11], 1199 ± 591 mg/1000 kcal/day in elderly of Viçosa, Brazil [34], and 854 ± 331 mg/1000 kcal/day [28]. Compared to these other studies, the mean polyphenol intake and the mean polyphenol intake adjusted by energy in the HELENA study sample was lower, i.e., 329 mg/day and 160 mg/1000 kcal/day. One reason for lower intakes might be the low consumption of polyphenol-rich food groups like fruit, vegetables and coffee/tea, which was the major food sources in previous studies. Indeed, total polyphenol intake probably reaches 1 g/day in people who eat several servings of fruit and vegetables per day [2], which is three times higher than the HELENA study as the adolescents only eat half of the recommended amount of fruit and vegetables [35]. Interesting is also the range of inter-individual differences (e.g., Supplemental Fig. 1) with only few reaching the 1 mg/day intake. The same large range was seen when comparing countries, e.g., mean intake of total polyphenols was three times higher in boys from Ghent (588 mg/day) than in boys from Zaragoza (212 mg/day).

Food group contributions

The main food contributors of polyphenols in this study were fruit (majority apple and pear), chocolate products; fruit and vegetable juices.

Interestingly, fruit and vegetables intakes in this study only reached half of the daily recommendation [36]. Especially for vegetables, this can be a reason for the lower contribution to polyphenol intakes compared to adult populations. Indeed, the daily vegetables consumption was low (164 g/person/day), and this low contribution was also noticed for flavanols in German adolescents [13]. On the other hand, fruit was an important polyphenol contributor although the consumption was similar as for vegetables (Table 2). This is in line with the Australian population where apple was the important flavonoid source for young people [14], and the contribution of fruit to flavonoid intake was higher than vegetables' contribution [37].

Chocolate products were the second major contributors of polyphenols in this study and adolescents consumed more sweets, which included chocolate products, than recommended [36]. Chocolate products were the third major food sources in the HAPIEE study [28], but in other studies chocolate products were not major food sources [12, 17, 30]. Higher chocolate consumption in the young can be because of their preferences to sweets and snacks [38].

Although coffee was the major food source of polyphenols in some studies [10, 12, 17, 34], this was not the case in the HELENA study sample as adolescents drink less coffee. Coffee was a minor contributor of per capita fluid intake in this study, whereas water, sugar-sweetened beverages and fruit juices were the largest contributors [39]. This can also explain why fruit juices were the third major contributions of polyphenols in the HELENA study.

Table 3 Contributions of food groups to total polyphenols and polyphenol classes (%) in the HELENA (Healthy Lifestyle in Europe by Nutrition in Adolescents) Study

Food items	Polyphenols (%)			Flavonoids (%)			Phenolic acids (%)		
	MED countries	Non-MED countries	All	MED countries	Non-MED countries	All	MED countries	Non-MED countries	All
Potatoes and other tubers	0	0.1	0.1	0	0	0	0	0.5	0.4
Vegetables	2.2	1.4	1.7	0.4	0.2	0.4	9.2	5.7	6.7
Leafy vegetables	0.9	0.3	0.5	0.1	0.02	0.1	3.8	1.5	2.1
Fruiting vegetables	0.7	0.7	0.7	0.1	0.1	0.1	3.2	3	3.1
Root vegetables	0.1	0.2	0.2	0	0	0	0.6	0.7	0.7
Cabbages	0.01	0	0	0	0	0	0	0.01	0.01
Grain and pod vegetables	0.01	0	0.01	0.01	0.01	0.01	0	0	0
Onion, garlic	0.01	0.02	0.02	0.02	0.03	0.03	0	0.01	0.01
Stalk vegetables, sprout	0.4	0.1	0.2	0.1	0.04	0.1	1.5	0.3	0.6
Mixed salad, mixed vegetables	0.1	0.1	0.1	0.02	0.03	0.03	0.1	0.2	0.2
Legumes	0.01	0.5	0.4	0.01	0.6	0. 5	0.03	0.1	0.1
Fruit	24.2	22.4	23	27.1	25.1	25.6	19.1	15.9	16.5
Citrus fruit	2.5	1	1.4	3.3	1.3	1.8	0.05	0	0.01
Apple and pear	13.9	17.1	16.3	16.3	19.8	18.9	10.5	11.1	10.9
Grape	0	0	0	0	0	0	0.01	0.01	0.01
Stone fruits	1.2	0.8	0.9	0.9	0.8	0.8	2.8	1.3	1.6
Berries	4.1	1.7	2.3	5.4	2.1	2.9	1.2	0.7	0.8
Other fruits	0.9	0.8	0.9	1.1	0.9	1	0.8	0.7	0.7
Olives	1.6	1	1.2	0.1	0.2	0.2	3.7	2.1	2.5
Nuts	1.4	0.8	0.9	0.9	0.5	0.6	3.7	2	2.4
Seeds	0.02	0.1	0.1	0	0.02	0.01	0.1	0.1	0.1
Dairy products	1. 6	2.9	2.6	2.1	3.9	3.4	0.2	0.3	0.3
Cereal products	9.5	8.5	8.8	1.6	1.6	1.5	20.3	16.9	17.7
Flour, flakes, starches, semolina and pastry	0.8	0.2	0.4	0.8	0.2	0.3	0.9	0.3	0.4
Pasta, rice, other grains	1.7	1.9	1.9	0.02	0.01	0.01	3.5	4.2	4
Bread, crispbread, rusks and crackers	3.1	3.7	3.5	0.1	0.3	0.2	7.9	5.4	6
Breakfast cereals	3.9	2.7	3	0.7	1.1	1	8	7	7.3
Cakes, biscuits and sweets	30.5	29	29.4	38.1	35.3	36	12.1	12.1	12.1
Cakes and biscuits	8.1	7	7.3	10.1	9	9.3	1.9	1	1.2
Chocolate products	20.5	18.7	19.2	27.9	24.8	25.6	1.1	0.9	0.9
Confectionary non-chocolate, candied fruits	0	0.5	0.4	0	0.5	0.4	0	0.5	0.4
Savoury snack	1.8	1.9	1.8	0.1	0.03	0.04	8.6	9	8.9
Ice cream, water ice	0.01	0.03	0.02	0.01	0.04	0.03	0	0.01	0.01
Sugar, honey, jam and syrup	0.1	0.9	0.7	0.04	0.9	0.7	0.4	0.8	0.7
Meat, fish and eggs	0	0	0	0	0	0	0	0	0
Fats and oils	1.8	0.04	0.5	0.1	0	0.01	0.1	0.1	0.1
Vegetable oils	1.8	0.04	0.5	0.1	0	0.01	0.1	0.1	0.1
Butter and animal fats	0	0	0	0	0	0	0	0	0
Non-alcoholic beverages	27.9	33.5	32.1	28.8	32.2	31.4	34.7	45.5	42.8
Fruit and vegetable juices	18.2	14.7	15. 6	23.6	18.1	19.5	5.1	5.1	5.1
Carbonated/soft/isotonic drinks	1	2.2	1.9	1.3	2.4	2.1	0.5	1.8	1.5
Coffee	5.1	6.2	5.9	0	0.3	0.2	25.8	29.1	28.3
Tea	3.5	10.4	8.7	4	11.3	9.5	3.3	9.5	8

Table 3 (continued)

Food items	Polyphenols (%)			Flavonoids (%)			Phenolic acids (%)		
	MED countries	Non-MED countries	All	MED countries	Non-MED countries	All	MED countries	Non-MED countries	All
Herbal tea	0	0.02	0.02	0	0.01	0.01	0	0.1	0.1
Other non-alcoholic beverages	0	0	0	0	0	0	0	0	0
Alcoholic beverages	0.4	0.3	0.3	0.4	0.2	0.3	0.4	0.4	0.4
Wine	0.4	0.2	0.2	0.4	0.2	0.2	0.3	0.2	0.2
Beer, cider	0.03	0.1	0.1	0.01	0.02	0.02	0.1	0.2	0.2
Spirits and cocktails	0	0.01	0.01	0	0.01	0.01	0	0	0
Condiments, spices, and sauces	0.2	0.3	0.3	0.1	0.1	0.1	0.3	0.4	0.4
Soy products	0.2	0.2	0.2	0.3	0.2	0.2	0.01	0	0
Other products	0.2	0.2	0.2	0.2	0.2	0.2	0.01	0.02	0.02

Food items	Lignans (%)			Stilbenes (%)			Other polyphenols (%)		
	MED countries	Non-MED countries	All	MED countries	Non-MED countries	All	MED countries	Non-MED countries	All
Potatoes and other tubers	0.1	0.2	0.1	0	0	0	0	0	0
Vegetables	6.7	7.5	7.1	0	0	0	0.9	0.1	0.3
Leafy vegetables	0.7	0.5	0.6	0	0	0	0.01	0.01	0.01
Fruiting vegetables	2.5	2.9	2.7	0	0	0	0.5	0.1	0.2
Root vegetables	0.6	1.4	1	0	0	0	0	0	0
Cabbages	0.9	0.7	0.8	0	0	0	0	0	0
Grain and pod vegetables	0.4	0.3	0.4	0	0	0	0	0	0
Onion, garlic	0.2	0.1	0.1	0	0	0	0	0	0
Stalk vegetables, sprout	1.1	0.6	0.9	0	0	0	0	0	0
Mixed salad, mixed vegetables	0.3	1	0.6	0	0	0	0.4	0.03	0.1
Legumes	0.3	0.7	0.5	0	0.6	0.4	0	0	0
Fruit	7.6	12.3	9.9	0.9	27.2	30.2	12.1	11.2	11.5
Citrus fruit	3.3	3.9	3.6	0	0	0	1.6	1	1.2
Apple and pear	1.4	2.4	1.9	0	0	0	0.02	0.01	0.02
Grape	0.2	0.6	0.4	0	0	0	0	0	0
Stone fruits	0.3	0.7	0.5	0	0	0	0	0	0
Berries	1.3	2.3	1.8	0	25.9	29.1	0	0	0
Other fruits	1.1	2.3	1.7	0.8	1.3	1.1	0.03	0.04	0.04
Olives	0.03	0.1	0.1	0	0	0	10.4	10.1	10.2
Nuts	0.1	0.3	0.2	0.6	1.3	1.1	0.02	0.1	0.04
Seeds	0.1	0.1	0.1	0	0.1	0.1	0.2	0.5	0.4
Dairy products	0.1	0.2	0.1	1	2.7	2.1	0.03	0.02	0.03
Cereal products	73.7	65.9	69.9	0	0.1	0.1	54.2	79.8	71
Flour, flakes, starches, semolina and pastry	1.2	1	1.1	0	0	0	0.8	0.3	0.5
Pasta, rice, other grains	0.8	2.6	1.7	0	0	0	14.1	22.1	19.4
Bread, crispbread, rusks and crackers	70.9	57.8	64.5	0	0.1	0.1	14	49.2	37.1
Breakfast cereals	0.8	4.5	2.7	0	0	0	25.2	8.1	14
Cakes, biscuits and sweets	2.7	6.5	4.5	5.6	14	11	5.9	2.2	3.4
Cakes and biscuits	2.3	3.8	3	0.5	2.3	1.7	5.8	1.7	3.1
Chocolate products	0.2	0.7	0.4	5	8.1	7	0.02	0.1	0.1
Confectionary non-chocolate, candied fruits	0	0.4	0.2	0.1	0.4	0.3	0	0.3	0.2

Table 3 (continued)

Food items	Lignans (%)			Stilbenes (%)			Other polyphenols (%)		
	MED countries	Non-MED countries	All	MED countries	Non-MED countries	All	MED countries	Non-MED countries	All
Savoury snack	0.2	1.3	0.7	0	0.3	0.2	0.1	0.1	0.1
Ice cream, water ice	0	0.01	0	0	0.1	0.1	0	0	0
Sugar, honey, jam and syrup	0	0.3	0.1	0	2.7	1.8	0	0	0
Meat, fish and eggs	0	0.1	0.03	0	0	0	0	0	0
Fats and oils	6.2	0.4	3.4	0	0.01	0	23.7	0.5	8.5
Vegetable oils	6.2	0.4	3.4	0	0.01	0	23.7	0.5	8.5
Butter and animal fats	0	0	0	0	0	0	0	0	0
Non-alcoholic beverages	1.8	4.5	3.1	0	2.6	1.7	1.7	3.1	2.6
Fruit and vegetable juices	1.6	3.1	2.3	0	0	0	0.9	1.6	1.3
Carbonated/soft/isotonic drinks	0.02	0.1	0.1	0	2.6	1.7	0.01	0.02	0.02
Coffee	0.1	0.2	0.1	0	0	0	0.9	1.6	1.3
Tea	0.1	1.1	0.6	0	0	0	0	0	0
Herbal tea	0	0.01	0	0	0	0	0	0	0
Other non-alcoholic beverages	0	0	0	0	0	0	0	0	0
Alcoholic beverages	0.1	0.5	0.3	56.9	51.1	53.1	0.2	0.5	0.4
Wine	0.1	0.2	0.1	56.9	51.1	53.1	0.2	0.2	0.2
Beer, cider	0.04	0.3	0.2	0	0	0	0.1	0.3	0.2
Spirits and cocktails	0	0.03	0.02	0	0	0	0	0.01	0.01
Condiments, spices, and sauces	0.5	1.1	0.8	0.2	0.2	0.2	1.2	2.3	1.9
Soy products	0.1	0.1	0.1	0	0	0	0.01	0	0
Other products	0	0.01	0.01	0	0.1	0.1	0	0	0

Values are percentages contribution to the intake of total polyphenols and polyphenol classes

MED countries Mediterranean countries

Classes, subclasses, and individual polyphenols

Interestingly, 384 different individual polyphenols have been recorded, which is a similar number as in the HAPIEE study [28] and in the French SU.VI.MAX study [17] that used the same database of polyphenols. 20 of them were consumed in higher amount than 1 mg/day, whereas in other studies around 100 individual polyphenols were consumed in amounts greater than 1 mg/day [11, 12, 17, 28]. Some of the polyphenols consumed by the European adolescents were different, for instance there were no 5-tricosylresorcinol and 5-heptadecylresorcinol in the top 25 most consumed individual polyphenols in previous studies [12, 17, 28].

Flavonoids were the most consumed polyphenol class. The highest subclass contributors to total polyphenols were also in this flavonoid class: the flavanols and flavanones. The flavanols had 64% contribution to the flavonoids intake, and more specifically by proanthocyanidin polymers, proanthocyanidin 4–6 oligomers and proanthocyanidin 7–10 oligomers, which was similar as in the EPIC study [12, 40]. Moreover, proanthocyanidins intake was higher in non-MED countries than in MED countries, due to higher intake of chocolate products, apple and pear consumption. In contrast, flavanones intake was higher in MED countries than in non-MED countries, due to higher consumption of fruit and vegetable juices. In MED countries, fruit were the most important food sources of flavonoids [41].

Intake of phenolic acids, especially hydroxycinnamic acids was higher also in non-MED countries than in MED countries, with coffee as the first rank contributor. This is consistent with previous studies [12, 42], but the intake of phenolic acids was lower than in previous studies. Again, as mentioned above, coffee was not frequently consumed by adolescents.

Lignans and stilbenes were higher in MED countries compared to non-MED countries, but their contribution to total polyphenols, i.e., below 0.5% was low, as observed earlier [12, 17, 29, 30]. Lariciresinol, which was one of the three most widely consumed lignans in the EPIC study [12], was also the biggest contributor to lignans in this study, due to higher intake of bread. Current results of very low stilbenes with wine as the major contributor also agree with previous studies [11, 12, 30]. Consistent with an earlier study, alkylphenols (2.8–3.1% contribution;

Table 4 Contribution of classes and subclasses of total polyphenols, number of individual polyphenols, and the top three most consumed individual polyphenols

Polyphenol classes and subclasses	MED countries (%)		Non-MED countries (%)		Number of individual polyphenols	Top three most consumed individual polyphenols
	Boys	Girls	Boys	Girls		
Total polyphenols	100	100	100	100	384	Proanthocyanidin polymers, hesperidin, proanthocyanidin 4–6 oligomers
Flavonoids	75.9	74.6	76.1	76.4	206	Proanthocyanidin polymers, hesperidin, proanthocyanidin 4–6 oligomers
Anthocyanins	0.02	0.02	0.01	0.005	58	Pelargonidin 3-*O*-glucoside, cyanidin 3-*O*-rutinoside, cyanidin 3-*O*-glucoside
Chalcones	0.000	0.000	0.001	0.001	1	Xanthohumol
Dihydrochalcones	0.8	0.7	1.1	0.9	3	Phloridzin, phloretin 2′-*O*-xylosyl-glucoside, 3-hydroxyphloretin 2′-*O*-glucoside
Dihydroflavonols	0.2	0.2	0.2	0.1	2	Dihydromyricetin 3-*O*-rhamnoside, dihydroquercetin 3-*O*-rhamnoside
Flavanols	48.6	47.7	51.8	54.3	26	Proanthocyanidin polymers, proanthocyanidin 4–6 oligomers, proanthocyanidin 7–10 oligomers
Flavan-3-ol monomer	3.4	4.3	5.6	7	9	(−)-Epicatechin, (+)-catechin, (+)-gallocatechin
Proanthocyanidins	33.5	36.7	38.7	40.6	13	Proanthocyanidin polymers, proanthocyanidin 4–6 oligomers, proanthocyanidin 7–10 oligomers
Theaflavins	11.6	6.7	7.5	6.8	4	Theaflavin 3,3′-*O*-digallate, theaflavin 3′-*O*-gallate, theaflavin
Flavanones	20.6	20.2	18.8	16.3	17	Hesperidin, didymin, eriocitrin
Flavones	2.7	3.3	2.0	1.8	31	Apigenin 6,8-di-C-glucoside, apigenin 6,8-C-galactoside-C-arabinoside, apigenin 6,8-C-arabinoside-C-glucoside
Flavonols	1.0	1.1	1.8	2.1	55	Quercetin 3-*O*-galactoside, quercetin 3-*O*-rutinoside, quercetin
Isoflavonoids	2.1	1.4	0.4	0.9	13	Genistin, 6-*O*-malonylgenistin, daidzin
Phenolic acids	16.8	18.1	19	18.8	99	5-Caffeoylquinic acid, ferulic acid, 4-caffeoylquinic acid
Hydroxybenzoic acids	0.8	1.1	1.4	1.8	27	Gallic acid, 5-*O*-galloylquinic acid, syringic acid
Hydroxycinnamic acids	15.8	16.8	17.4	16.8	61	5-Caffeoylquinic acid, ferulic acid, 4-caffeoylquinic acid
Hydroxyphenylacetic acids	0.02	0.02	0.01	0.01	4	4-Hydroxyphenylacetic acid, homovanillic acid, 3,4-dihydroxyphenylacetic acid
Hydrophenylpropanoic acids	0.2	0.2	0.2	0.2	1	Dihydro-*p*-coumaric acid
Stilbenes	0.014	0.012	0.007	0.006	7	Resveratrol, resveratrol 3-*O*-glucoside, piceatannol 3-*O*-glucoside
Lignans	0.4	0.4	0.2	0.2	23	Lariciresinol, syringaresinol, pinoresinol
Other polyphenol class	7	6.9	4.7	4.6	58	5-Heneicosylresorcinol, oleuropein-aglycone, phlorin
Alkylmethoxyphenols	0.6	0.4	0.4	0.3	3	4-Vinylsyringol, 4-vinylguaiacol, 4-ethylguaiacol
Alkylphenols	2.8	2.7	3.1	3.0	14	5-Heneicosylresorcinol, 5-nonadecylresorcinol, 5-tricosylresorcinol
Tyrosol	3.2	3.4	0.6	0.5	13	3,4-DHPEA-EDA, oleuropein-aglycone, *p*-HPEA-EDA
Other polyphenols subclass	0.4	0.4	0.6	0.8	28	Phlorin, eugenol, curcumin
Cucurminoids	0.002	0.2	0.2	0.1	1	Curcumin
Furanocoumarins	0.2	0.1	0.1	0.1	4	Bergapten, psoralen, isopimpinellin
Hydroxybenzaldehydes	0.002	0.002	0.003	0.002	4	Vanillin, syringaldehyde, protocatechuic aldehyde
Hydroxybenzoketones	0.001	0.001	0.002	0.001	1	2,3-Dihydroxy-1-guaiacylpropanone
Hydroxycoumarins	0.002	0.001	0.004	0.001	4	4-Hydroxycoumarin, mellein, esculin
Hydroxyphenylpropenes	0.0	0.0	0.1	0.3	3	Eugenol, acetyl eugenol, [6]-gingerol
Methoxyphenols	0.037	0.022	0.05	0.034	1	Guaiacol
Naphtoquinones	0.01	0.01	0.01	0.004	1	Juglone
Other polyphenols family	0.2	0.1	0.1	0.1	6	Phlorin, pyrogallol, catechol

Value are percentages derived from general linear models adjusted for sex, age, European region, energy intake and months of recall

MED countries Mediterranean countries

mainly present in bread) and tyrosol (0.5–3.4%; present in olive oil) were the main polyphenol contributors within the other polyphenols class [12].

Socio-demographic and lifestyle determinants

Socio-demographic (age, sex, European region, economic status) and lifestyle factors (BMI and alcohol use) influenced

Table 5 Intake of the top 25 most consumed individual polyphenols and their main food sources in the HELENA study

Polyphenol	Polyphenol subclass	All		MED countries				Non-MED countries				Main food sources (% contribution to individual polyphenols)
				Boys		Girls		Boys		Girls		
		Mean	se	Mean	se	Mean	se	Mean	se	Mean	se	
Proanthocyanidin polymers (> 10 mers)	Flavanols	37	0.0	23	0.1	28	0.0	43	0.0	57	0.0	Chocolate products (42%), apples and pears (23.4%), cakes and biscuits (15.5%)
Hesperidin	Flavanones	31	0.0	26	0.1	27	0.1	36	0.0	39	0.0	Fruit and vegetable juices (86.9%), citrus fruits (6.1%), carbonated/soft drinks (5.8%)
Proanthocyanidin 4–6 oligomers	Flavanols	28	0.0	18	0.0	21	0.0	33	0.0	44	0.0	Chocolate products (42%), apples and pears (26.1%), cakes and biscuits (15.3%)
Proanthocyanidin 7–10 oligomers	Flavanols	17	0.0	10	0.0	13	0.0	20	0.0	27	0.0	Apples and pears (35.9%), chocolate products (34.3%), cakes and biscuits (14%)
5-Caffeoylquinic acid	Hydroxycinnamic acids	15	0.0	10	0.0	12	0.0	18	0.0	22	0.0	Coffee (33.1%), apples and pears (30.2%), fruit and vegetable juices (13.7%)
Ferulic acid	Hydroxycinnamic acids	10	0.0	9	0.0	7	0.0	12	0.0	13	0.0	Breakfast cereals (28.4%), bread (26%), pasta, rice and other grains (13.4%)
Proanthocyanidin trimers	Flavanols	10	0.0	5	0.0	6	0.0	12	0.0	16	0.0	Chocolate products (54.6%), apples and pears (19.1%), cakes and biscuits (13.1%)
(−)-Epicatechin	Flavanols	7	0.0	4	0.0	5	0.0	9	0.0	12	0.0	Chocolate products (33.8%), apples and pears (33%), tea (12.5%)
Procyanidin dimer B2	Flavanols	5	0.0	2	0.0	3	0.0	6	0.0	9	0.0	Apples and pears (63.4%), chocolate products (14.5%), tea (9.8%)
(+)-Catechin	Flavanols	4	0.0	3	0.0	3	0.0	4	0.0	6	0.0	Chocolate products (27.9%), tea (15.8%), fruit and vegetable juices (12.1%)
5-Heneicosylresorcinol	Alkylphenols	4	0.0	2	0.0	2	0.0	5	0.0	5	0.0	Bread (49.2%), pasta, rice and other grains (30.4%), breakfast cereals (17.2%)
5-Nonadecylresorcinol	Alkylphenols	3	0.0	2	0.0	1	0.0	4	0.0	4	0.0	Bread (65.7%), pasta, rice, and other grains (17.4%), breakfast cereals (14.3%)
Apigenin 6,8-di-C-glucoside	Flavones	2	0.0	2	0.0	2	0.0	2	0.0	3	0.0	Fruit and vegetable juices (79.3%), citrus fruit (17.8%), carbonated/soft drinks (1.8%)
4-Caffeoylquinic acid	Hydroxycinnamic acids	2	0.0	2	0.0	2	0.0	3	0.0	3	0.0	Coffee (88.1%), tea (5.7%), fruiting vegetables (2.7%)
3-Caffeoylquinic acid	Hydroxycinnamic acids	2	0.0	1	0.0	2	0.0	2	0.0	3	0.0	Coffee (78.7%), stone fruit (10.2%), fruit and vegetable juices (5.6%)
Didymin	Flavanones	2	0.0	2	0.0	2	0.0	2	0.0	2	0.0	Fruit and vegetable juices (71.4%), citrus fruit (25.7%), carbonated/soft drinks (1.6%)
Procyanidin dimer B1	Flavanols	2	0.0	1	0.0	1	0.0	2	0.0	3	0.0	Tea (38.9%), apples and pears (18.5%), cakes and biscuits (15.4%)
Apigenin 6,8-C-galactoside-C-arabinoside	Flavones	1	0.0	1	0.0	2	0.0	1	0.0	1	0.0	Flour, flakes, starches, sesomina and pastry (31.4%), cakes and biscuits (27.2%), breakfast cereals (24.6%)
5-Tricosylresorcinol	Alkylphenols	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	Pasta, rice, and other grains (48%), bread (37.5%), breakfast cereals (12.3%)

Table 5 (continued)

Polyphenol	Polyphenol subclass	All		MED countries				Non-MED countries				Main food sources (% contribution to individual polyphenols)
				Boys		Girls		Boys		Girls		
		Mean	se	Mean	se	Mean	se	Mean	se	Mean	se	
Eriocitrin	Flavanones	1	0.0	0.5	0.0	0.4	0.0	2	0.0	2	0.0	Carbonated/soft drinks (73.5%), fruit and vegetable juices (23.5%), citrus fruit (1.9%)
5-Heptadecylresorcinol	Alkylphenols	0.98	0.0	0.9	0.0	0.7	0.0	1	0.0	1	0.0	Bread (54.8%), pasta, rice and other grains (35.1%), breakfast cereals (8.6%)
Apigenin 6,8-C-arabinoside-C-glucoside	Flavones	0.9	0.0	0.8	0.0	1	0.0	0.8	0.0	0.8	0	Flour, flakes, starches, sesomina and pastry (31.5%), cakes and biscuits (27.3%), breakfast cereals (24.2%)
Cinnamtannin A2	Flavanols	0.8	0.0	0.5	0	0.6	0.0	0.9	0.0	1	0	Chocolate products (66.5%), cakes and biscuits (21.3%), dairy products (9.4%)
Gallic acid	Hydroxybenzoic acids	0.7	0.0	0.3	0.0	0.4	0.0	0.9	0.0	1	0.0	Tea (57.5%), nuts (22.6%), other fruit (9.2%)
Phloridzin	Dihydrochalcones	0.7	0.0	0.2	0.0	0.3	0.0	1	0.0	1	0.0	Apples and pears (68.6%), carbonated/soft drinks (18.2%), fruit and vegetable juices (11.3%)

Mean and standard error (s.e.) were derived from general linear models adjusted sex, age, European region, energy intake and months of recall

MED Mediterranean

the intake of total polyphenols and polyphenol classes. Contrary to earlier studies in which men had higher absolute total polyphenol intake compared to women [10, 12, 34], especially for flavonoids [40, 43], girls had a higher intake than boys in the HELENA study, even after adjusting for total energy intake. This is due to higher consumption of fruit and chocolate products (the main contributors) in girls [36], while in a previous study, coffee consumption (the main contributor) was higher in men. Polyphenol intake increased by age, especially phenolic acid intakes, due to differential consumption of coffee and tea. In the HELENA study, adolescents aged 15.0–17.5-years-old, consumed more coffee and tea than younger adolescents [36]. This age difference was also detected in Australian adolescents [14].

Intakes of total polyphenols and several polyphenol classes differed by European region. Non-MED countries had higher contributions of flavonoids and phenolic acids, which were the most contributing polyphenol classes to total polyphenols. This finding is similar as in the EPIC study [12], due to higher consumption of apple and pear, tea and coffee. Indeed, coffee was the major food source of polyphenols in non-MED countries [12, 42].

In the present study, polyphenol intakes were depending on BMI, consistent with other research [12]. Polyphenol intakes were also higher in those with higher parental education, as in previous studies [10, 12]. Indeed, parental education in this population was associated with higher diet quality [44] and healthier food choices for breakfast [45, 46], thus with higher intake of polyphenol rich sources like fruit and vegetables. Seemingly in contrast, adolescents who reported lower family affluence had higher polyphenol intakes, flavonoid intakes, and lignan intakes compared to those reporting greater family affluence. This might be explained by the fact that adolescents with lower family affluence consume more tea (high polyphenol content, especially flavonoids) and coffee (high polyphenol content), cakes, pies, biscuits and snacks (important polyphenol contributors in our adolescents) for breakfast [46]. Although it should be mentioned that FAS was less relevant than parental education for healthy lifestyle clustering [44, 47]. Alcohol consumers also had higher polyphenol intakes. Only few adolescents consumed alcohol (23%), but alcoholic beverages (especially wine and beer) are sources of polyphenols.

Strengths and limitations

The major strengths of this study are the large and heterogeneous sample size, which gives an approximation of the average situation in European cities [18], the use of reliable and validated 24-h recalls [48] and the use of the Phenol-Explorer database as the most comprehensive database for polyphenols [12].

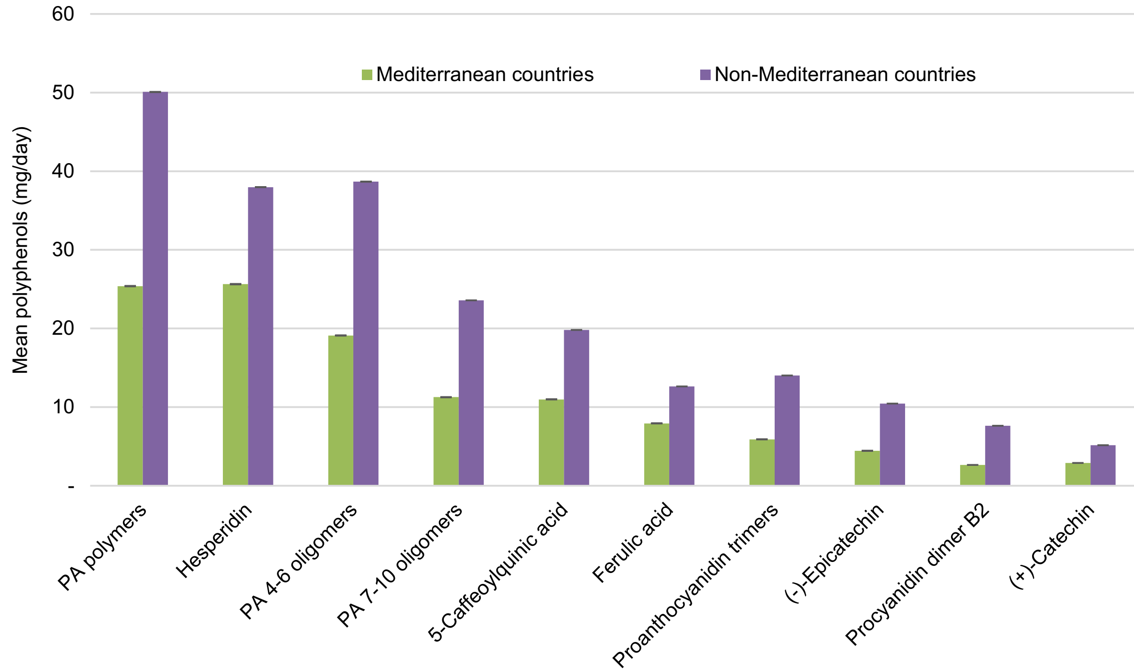

Fig. 2 Daily intake (mg/day), mean and standard error, of the top 10 polyphenols for Mediterranean countries and non-Mediterranean countries, adjusted for age, sex, energy intake and month of 24-h recall. *PA* proanthocyanidin

One limitation of this study is a lack of generalizability due to the cluster selection using only urban areas [18]. Missing data of Fridays and Saturdays might have induced a small bias/underestimation for alcoholic drinks which are mainly used in weekends. Also the use of self-reported data on lifestyle [48] and the lack of dietary reference intake values for dietary polyphenols [8] are limitations in this study. Finally, polyphenol intake estimation has some small difficulties like incomplete food composition data such as thearubigins [49] or proanthocyanidins concentrations [33]; some missing details in the 24-h recall like herbs, and specific oil type; and lacking food items in the Phenol-Explorer, such as palm oil, processed foods, cassava, various types of coffee, tea and honey. However, as the consumption of coffee, tea, and honey was low in this population [39]; they are almost negligible sources of polyphenols in this study.

Conclusion

For this first time, this study has provided detailed information of polyphenol intakes, its main food sources and its socio-demographic and lifestyle determinants in a diverse group of European adolescents. Total polyphenol intake (mean 329 mg/day) was lower compared to intake of adults reported in previous studies (even after energy-adjustment). The major food sources of polyphenols in adolescents were fruit, chocolate products; and fruit and vegetable juices. Polyphenol intake differed largely among countries, especially with lower overall intakes in MED compared to non-MED countries, although both regions had the same major food contributors. In the major food contributors, fruit was confirmed as in adult populations but chocolate and cakes/biscuits seemed specific ones in adolescents compared to adult samples. Other important determinants were sex, age, BMI, socio-economic status and alcohol use. Overall, these results show the importance of promoting a healthier diet intake in adolescents with, e.g., more fruit, vegetables and nuts to increase the currently low polyphenol intakes. The discussed determinants and polyphenol types already point to some important population groups that need to be prioritized and targeted in future public health initiatives. After all, polyphenol intake might ameliorate the future health of these youngsters.

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Author contributions RWW formulated the research question, has analysed the data, prepared the estimation of polyphenols, and wrote a draft of the paper. NM helped in refining the research question, setting up the database, analyzing the data and did editing of the first draft. NM, SH and LAM are PhD supervisors of RWW; LAM was the coordinator of the HELENA project. From the International Agency for Research on Cancer, we received help from AS, VK and IH in the linking to their Phenol-Explorer database containing the polyphenol concentrations in food items. All other authors were involved in the

HELENA project (coordinator or data collection in their country; this was a European study in 10 centers). All authors have read the draft and agreed on the final version.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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