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ORIGINAL CONTRIBUTION

Dietary intake of (poly)phenols in children and adults: cross-sectional analysis of UK National Diet and Nutrition Survey Rolling Programme (2008–2014)

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Abstract

Purpose Current evidence accounts for the role of (poly)phenolic compounds in the prevention of non-communicable diseases. Detailed information on population-level intakes is required to translate these findings into recommendations. This work aimed to estimate (poly)phenol intake in the UK population using data from a nationally representative survey.

Methods Data from 9374 participants (4636 children aged 1.5–18 years and 4738 adults aged 19 years and over) from the National Diet and Nutrition Survey Rolling Programme (NDNS RP) 2008–2014 was used. (Poly)phenol content of foods consumed in the NDNS RP was identified using Phenol-Explorer and through literature searches. Data on flavonoids, phenolic acids, and stilbenes were collected. Total (poly)phenol content was also assessed.

Results Mean total (poly)phenol intake ranged from 266.6 ± 166.1 mg/day in children aged 1.5–3 years to 1035.1 ± 544.3 mg/day in adults aged 65 years and over, with flavan-3-ols and hydroxycinnamic acids being the most consumed (poly)phenols across all age groups. (Poly)phenol intake was higher in males in all age groups except for adults aged 19–34 and 50–64 years, where intakes were marginally higher in females. Energy-adjusted intakes accounted for the pattern of increasing (poly)phenol intakes with age and a higher intake was observed in females across all age groups, with the exception of children aged 1.5–3 years. The main food sources were non-alcoholic beverages and fruits, being the main compounds flavan-3-ols and caffeoylquinic acids.

Conclusions This analysis provides estimates of (poly)phenol intake from a representative sample of the UK general population, which can help inform the health implications of (poly)phenol intake.

Keywords Polyphenol · Flavonoid · Dietary intake · Food source · NDNS

Introduction

(Poly)phenolic compounds are plant secondary metabolites present in plant-based foods able to impact on human health [1–3]. They are a complex family of phytochemical

Nida Ziauddeen and Alice Rosi contributed equally to this work.

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compounds ranging from simple phenols and phenolic acids to high molecular weight polymeric structures such as hydrolysable and condensed tannins. Dietary (poly)phenols can be classified into two main groups: flavonoids and non-flavonoids. Flavonoids are polyphenolic compounds comprising a 15-carbon moiety and having two aromatic rings and a heterocyclic ring. Among the different flavonoid subclasses, flavonols, flavones, flavanones, flavan-3-ols (both catechin monomers and polymeric proanthocyanidins), isoflavones, and anthocyanins are the most important from a dietary point of view. Non-flavonoids include phenolic acids like hydroxybenzoic and hydroxycinnamic acids, stilbenes, and hydrolysable tannins (gallotannins, ellagitannins, and phlorotannins). Upon consumption, most of these compounds are deeply metabolised and appear in circulation as phase II metabolites able to exert specific biological activities related to health promotion [1–3]. The role of several phenolic compounds in the prevention of non-communicable diseases, such as cardiovascular diseases (CVD), type 2 diabetes mellitus, neurodegeneration, and some types of cancer, has been described by several observational studies [4–8]. In addition, higher intake of (poly)phenols has been associated with a more favourable cardiovascular risk profile in adults with type 2 diabetes [9]. However, despite the wide number of phenolic compounds known to be present in plant-based foods, research has usually been limited to certain subclasses or compounds or foods known to be rich in (poly)phenols.

Despite evidence on the benefits of consumption of (poly)phenol-rich foods, detailed information on population-level intakes is required to translate these findings into recommendations. Currently, information is limited to specific populations, and the evaluation of (poly)phenol intakes is difficult, as different analytical techniques cause heterogeneity across publications. Data on (poly)phenol intake in the UK have been limited to two studies: an adult cohort aged 35–74 years who participated in the European Prospective Investigation into Cancer and Nutrition Study (EPIC) [10, 11], and adults aged 19–64 from the National Diet and Nutrition Survey (NDNS) of Adults (2000/01) [12]. Although the EPIC cohort is recruited from the general population, the study participants were recruited from within defined geographical areas and it is unlikely to be representative of the general population. The NDNS of adults (2000/01) was representative of the general adult population, but this analysis was part of a wider analysis of (poly)phenol intake in Europe and only certain compounds and subclass were assessed. To our knowledge, there have been no reports of (poly)phenol intake in UK children and adolescents and no comprehensive study of the dietary intake of (poly)phenolic compounds in adults. Thus, the aim of this study was to examine (poly)phenol intake in a representative sample of the UK general population aged 1.5 years and over.

Methods

Sample

Data were collected between 2008 and 2014 as part of the UK NDNS Rolling Programme (RP). This trial was registered with the ISRTCN registry as ISRCTN17261407. The NDNS RP is designed to assess the diet, nutrient intake, and nutritional status of the UK population aged 1.5 years and over living in private households. The survey aims to recruit 1000 participants per year (core sample, 500 children aged 1.5–18 years, and 500 adults aged 19 years and over) and up to 600 additional participants (boost sample). Details of the NDNS RP design and sampling methods have been previously published [13], but a brief outline is provided below. A random sample is drawn from a list of all the addresses in the UK called the Postcode Address File. Addresses are clustered into primary sampling units (PSUs) which are smaller geographical areas based on postcode sectors and a random selection from across the UK are selected. From each PSU, 27 addresses were randomly selected, and information describing the purpose of the study was posted to the selected addresses. Trained interviewers then contacted these addresses to recruit participants and place diet diaries.

Dietary data

NDNS RP dietary data were collected using 4-day estimated diaries with participants asked to keep a record of everything eaten or drunk over four consecutive days. Only participants who completed 3 or 4 diary days were included (2%, equal to 84 participants completed three diary days and 98%, equal to 9290 participants completed four diary days). The parent/carer was asked to complete the diary for children aged 12 years or younger with input from the child as needed. Participants were asked to record all food and beverages consumed with portion sizes including brand names and recipes for home cooked foods. Food labelling information for branded packaged products and proportions for recipes were used to code portion sizes. Other portion sizes were generally estimated and recorded in household measures (spoonfuls, glasses/cups) and were informed using standardised pictures provided in the front of the diary. Participants were asked to provide packaging for foods consumed during the recording period to aid data coding.

Interviewers undertook three visits with each household. At the first visit, the interviewer administered the Computer Assisted Personal Interview (CAPI) and placed the diary. The second visit was a brief visit (in person or by telephone)

to provide check for compliance and provide support during diary completion. At the third visit, the diary was reviewed, edited for possible omissions and collected.

Trained coders coded the NDNS RP diaries using a dietary assessment system, Diet In Nutrients Out (DINO) [14]. Each recorded that item was assigned a suitable food and portion code. Food composition data from the UK NDNS Nutrient Databank were used [15]. Standard portion size information was obtained from the Food Standard Agency's portion size book [16] and published age appropriate portion sizes for children [17]. Composite dishes that could be split into their component parts, such as sandwiches, were coded as individual separate components. The same approach was applied to homemade dishes for which recipes had been provided in the diary, but these were then additionally linked together to indicate being cooked together.

(Poly)phenol content and intakes

4493 food codes were coded against in the NDNS RP Years 1–6. Phenol-Explorer (http://phenol-explorer.eu), the comprehensive online database that contains data on the content of over 502 (poly)phenols in over 400 foods [18, 19], was used to identify the (poly)phenol content of foods consumed in the NDNS RP. Data on all the available compounds belonging to the flavonoid and phenolic acid classes of interest were considered: anthocyanins, flavan-3-ols (both monomers and proanthocyanidins), flavanones, flavones, flavonols, isoflavones, theaflavins, chalcones, hydroxybenzoic acids, hydroxycinnamic acids, and hydroxyphenylpropanoic acids, as well as stilbenes and total phenol content through the Folin assay method.

All raw foods with known (poly)phenol content were matched univocally to those listed in Phenol-Explorer. Food entries that could correspond to multiple food items in Phenol-Explorer were matched to the food item deemed to be most popularly consumed by the UK population (for instance, onions were matched to white onions, and tea was linked to black tea). Phenolic content for dishes or complex foods including various ingredients (e.g., muesli and apple pie) was calculated by taking into account each individual ingredient and its corresponding proportion in the food. The information on the proportion of ingredients in the complex foods was determined from the UK Standard Recipes Database which provides information on the amount of ingredients for each homemade and manufactured food containing more than one ingredient [20]. Due to lack of available data on the effect of different cooking and processing methods, this was not accounted for. However, weight change during cooking and/or processing was taken into account by applying yield factors obtained from Bognar's tables [21] or from Phenol-Explorer [19]. If there were missing data in the yield factors, the (poly) phenol content was obtained from values of the raw food. For example, (poly)phenol content was collected from a generic juice when specific values and yield factors for bottled, canned, or pasteurised were not available.

(Poly)phenol content for foods that are likely to contain some amount of phenolic compounds but that could not be matched to a suitable item in the Phenol-Explorer database was obtained from values of the most similar food or from the most up to date scientific literature (examples include sprouts, dried fruits and berries, mushrooms, and cassava). Foods consumed only in very small amounts or containing only traces of phenolic compounds were not evaluated, because their contribution to (poly)phenol intake was considered insignificant. Foods that contain no amount of plant (poly)phenols were excluded.

Individual-level intakes of each (poly)phenolic compound were calculated by multiplying the amount of food or beverage consumed with the (poly)phenol content in 100 g of the food or beverage. Total (poly)phenol content was calculated as the sum of all individual phenolics obtained by chromatography without hydrolysis, or by chromatography after hydrolysis if chromatographic values without hydrolysis were not available, for all the classes of compounds considered. In addition, normal-phase high-performance liquid chromatography (HPLC) data were considered for proanthocyanidins, except for proanthocyanidin dimers for which individual data, when available, was used. The total amount of phenolic compounds was also calculated as the sum of individual phenol contents determined by the Folin assay method.

Other variables

Body mass index (BMI) was calculated using height and weight measurements taken by trained interviewers. The measurements were taken using a portable stadiometer, measuring to the nearest 0.1 cm (rounded to the nearest even mm if between 2 mm) and weighing scales, measuring to the nearest 0.1 kg. Estimated height based on demispan was used to calculate BMI in participants, whose height could be measured. Income was self-reported. Data on frequency of drinking and smoking were collected through self-report using questions that were designed specifically for the NDNS CAPI. As the drinking and smoking data are collected from 8 years of age onwards and due to the small number who reported smoking ($n=1$) or drinking ($n=28$) in children aged 8–10 years, these are only reported for participants aged 11 years and over.

Data analysis

NDNS RP data are weighted to adjust for differences in sample selection and response. All analyses were carried out using the survey package in R v3.0.2 [22] to account for the stratification and clustering in the NDNS RP sample design.

All participants from the NDNS RP collected between 2008 and 2014 were included. Due to the wide age range (1.5–96 years) of participants included in the NDNS RP, results are presented stratified by age groups (1.5–3, 4–10, 11–18, 19–34, 35–49, 50–64, and 65 years or over). (Poly) phenol intake adjusted for energy intake was also calculated (mg of total (poly)phenols per 1000 kcal/day of total energy consumed).

Mean intakes over the 4 days (or 3 days in those who only filled out 3 days) were calculated. Intakes were calculated for all individual phenolic compounds, groups (flavan-3-ols, flavonols, flavanones, flavones, isoflavones, anthocyanins, theaflavins, chalcones, hydroxybenzoic acids, hydroxycinnamic acids, hydroxyphenylpropanoic acids, and stilbenes), and total phenolic content and food contributors were determined. Food categories with a very limited contribution to the total intake, as assessed on the basis of the results (for instance, artificial sweeteners, meat/fish products and dishes, etc.), were not presented. The intake of each individual (poly)phenol in the overall study population was calculated to determine the most consumed individual (poly)phenols. The mean intake of each (poly)phenol was calculated considering individual participants. The mean of the percentage intake by age group was used to determine the main food sources of the most commonly consumed individual (poly) phenols. Patterns in intake by descriptive factors were compared using linear regression adjusted for age groups.

Results

The sample consisted of 9374 participants (4636 children aged 1.5–18 years and 4738 adults aged 19 years and over). The sample was fairly evenly split between males and females amongst children, but there were more females amongst adults (Table 1). Total (poly)phenol intake increased with age ($p \leq 0.001$) and was higher in males in all age groups, except for adults aged 19–34 and 50–64 years, where intakes were marginally higher in females. The pattern of increasing intakes with age was also observed in energy-adjusted intake, but in this case, phenolic intakes were higher in females across all age groups ($p < 0.001$), with the exception of children aged 1.5–3 years (Supplementary Material Table 1). (Poly)phenol intakes were highest in the normal weight category (BMI 18.5–24.9 kg/m^2) across all age groups except in children aged 1.5–10 years, where intakes were highest in the obese category (BMI $\geq$ 30.0 kg/m^2) ($p < 0.001$). On the contrary, although (poly)phenol intakes were significantly different across BMI categories when intakes were adjusted for energy intake ($p < 0.001$), there was no clear pattern across the age groups. Intakes were significantly higher in non-smokers than in smokers ($p < 0.001$) and in alcohol drinkers than in non-drinkers ($p < 0.001$), and substantially so in older adults ($p < 0.001$). The pattern in alcohol drinkers and non-drinkers remained similar for energy-adjusted intake ($p < 0.001$). Country and income also had a significant effect on the total (poly)phenol intake for both non-adjusted and energy-adjusted data ($p < 0.001$).

The intake of total (poly)phenol and subclasses by age groups are presented in Table 2. The main class of phenolic compounds contributing to (poly)phenol intake was flavonoids. Flavan-3-ols were the most highly consumed (poly) phenolic subclass, followed by hydroxycinnamic acids. Intakes of total (poly)phenols as determined by the sum of the classes were less than intakes as determined through Folin assay (over double in young children and nearly double in most other age groups, except older adults, where the differences in intakes were of a slightly smaller magnitude). The same pattern was observed for energy-adjusted intake (Supplementary Table 2). Changes in the relative contribution of the most consumed classes and subclasses of phenolic compounds were also observed for the different age groups (Fig. 1).

Non-alcoholic beverages were the highest contributor to total (poly)phenol and flavonoid intake, followed by fruit (Table 3). The main contributors to total phenolic acids were non-alcoholic beverages and vegetables.

The 20 most consumed individual (poly)phenolic compounds, and the three highest food contributors are listed in Table 4. Of the most consumed (poly)phenols, three were hydroxycinnamic acids, 14 were flavan-3-ols, both monomers and oligomers, and one each were hydroxybenzoic acids, flavones and flavanones. Coffee, tea, potatoes, and tomatoes were the main contributors to hydroxycinnamic acids in adults, whereas the main contributors in children were fruit juice, potatoes, beans and pulses, tomatoes, and tea. Tea, chocolate, wine, fruit, and vegetables were the main contributors to flavan-3-ol intake in adults, while in children tea, fruit juice, fruit, and vegetables were the main dietary sources of flavan-3-ols. Tea was the main contributor to hydroxybenzoic acids in adults, whereas soft drinks, fruit, and tea were the main contributors in children.

Discussion

To our knowledge, this study presents the first comprehensive analysis of (poly)phenol intake in a nationally representative sample of the UK population including both adults and

Table 1 Total (poly)phenol intake (mg/day), as the sum of individual (poly)phenol compounds, by demographic characteristics

Characteristics	1.5–3 years		4–10 years		11–18 years		19–34 years		35–49 years		50–64 years		65 + years		*P* value
	N	Total intake	*N*	Total intake	*N*	Total intake	*N*	Total intake	*N*	Total intake	*N*	Total intake	*N*	Total intake	
Gender															
Male	418	276.4 ± 186.2	923	390.1 ± 184.6	1012	472.1 ± 277.5	408	634.0 ± 482.3	580	875.4 ± 534.5	511	1050.7 ± 573.4	447	1074.2 ± 592.9	0.09
Female	401	256.3 ± 141.5	849	387.3 ± 193.3	1033	437.1 ± 246.1	659	637.9 ± 413.2	841	817.0 ± 491.7	663	1055.5 ± 517.1	629	1004.2 ± 500.8	
BMI															
Underweight	–	–	–	–	–	–	26	747.8 ± 478.4	11	512.6 ± 291.4	9	1191.2 ± 556.2	12	739.4 ± 544.5	< 0.001
Normal weight	307	282.6 ± 155.5	1206	391.0 ± 190.9	1296	467.6 ± 260	495	685.1 ± 457.1	445	926.5 ± 926.5	282	1168.7 ± 549.3	232	1087.5 ± 586.8	
Overweight	115	268.2 ± 162.6	234	370.0 ± 162.9	287	451.6 ± 262	306	594.7 ± 403.2	507	845.2 ± 519.5	420	1090.8 ± 538.3	388	1074.1 ± 529.3	
Obese	103	317.0 ± 263	256	398.1 ± 207.1	397	422.7 ± 276.4	189	606.8 ± 495.6	376	777.9 ± 496.4	393	933.0 ± 513.2	299	976.4 ± 535.9	
Country															
England	466	265.4 ± 171.7	1005	391.6 ± 188.7	1073	457.1 ± 265.9	582	644.3 ± 454.3	776	852.1 ± 513.4	668	1079.8 ± 542.1	555	1046.7 ± 550.9	< 0.001
Scotland	148	276.8 ± 134.2	334	373.6 ± 198.7	424	429.4 ± 238.6	198	597.1 ± 438.2	289	806.3 ± 498.4	221	894.5 ± 533.1	244	967.3 ± 516.2	
Wales	98	274.9 ± 133.7	204	371.7 ± 179.3	238	458.4 ± 253.9	118	613.7 ± 432.8	176	784.1 ± 504.5	141	949.5 ± 569.1	176	1001.3 ± 539.5	
Northern Ireland	107	261.0 ± 120.4	229	375.5 ± 180.1	310	461.7 ± 266.2	169	540.1 ± 328.9	180	888.1 ± 590.9	144	958.9 ± 524.1	101	952.1 ± 392.7	
Income															
≤ £17,500	266	276.4 ± 203.8	596	365.2 ± 186.9	721	430.3 ± 248	354	582.5 ± 452.2	358	760.9 ± 534.9	265	979.0 ± 562.8	372	1000.0 ± 480	< 0.001
> £17,500 ≤ £32,383	255	258.2 ± 151.7	519	399.4 ± 189.3	591	467.7 ± 288.7	279	653.2 ± 420.5	382	804.6 ± 447.8	308	1015.7 ± 543.3	286	991.8 ± 544.7	
> £32,383	216	270.6 ± 132.1	479	418.2 ± 194.3	467	489.5 ± 255.3	312	708.8 ± 478.2	527	929.9 ± 531.8	438	1103.6 ± 501.6	181	1245.8 ± 656.9	
Smoking															
No	–	–	–	–	1772	451.5 ± 262.2	688	650.2 ± 432.4	974	862.8 ± 481.5	909	1071.9 ± 534.4	927	1046.6 ± 543.7	< 0.001
Yes	–	–	–	–	211	457.7 ± 261.4	378	609.1 ± 478.7	447	801.8 ± 590.6	265	972.9 ± 584	149	953.9 ± 543.4	
Drinking															
Once a week or more	–	–	–	–	227	490.9 ± 296.2	482	622.1 ± 456	682	894.0 ± 492.2	500	1079.5 ± 516.9	327	1078.4 ± 518.9	< 0.001
Once or twice a month	–	–	–	–	310	501.2 ± 308.8	253	643.0 ± 431.4	220	827.3 ± 484.2	143	1047.0 ± 554.2	105	1107.3 ± 541.4	
Once every couple of months	–	–	–	–	136	541.6 ± 303.8	108	736.5 ± 510.4	119	787.0 ± 478	88	1062.8 ± 627.5	85	928.4 ± 429.4	
Few times a year	–	–	–	–	392	445.6 ± 253	76	706.6 ± 496.2	104	739.8 ± 535.3	97	1011.3 ± 533.5	134	862.2 ± 520.5	
Never drinks	–	–	–	–	900	417.5 ± 220.7	116	574.9 ± 385.3	150	733.2 ± 564.4	148	770.9 ± 496	223	938.1 ± 451.3	

Values are presented as mean ± SD. *P* value was calculated using linear regression

Table 2 Intake of dietary (poly)phenols (mg/day) by age group and subclass of phenolic compounds

(Poly)phenolic compounds	1.5–3 years	4–10 years	11–18 years	19–34 years	35–49 years	50–64 years	65 + years
N	819	1772	2045	1067	1421	1174	1076
Total phenols (Folin assay)	566.6 ± 324.3	839.0 ± 775.7	851.0 ± 568.5	1172.1 ± 656.4	1528.0 ± 1091.2	1785.2 ± 839.3	1656.6 ± 809.3
Total (poly)phenols[a]	266.6 ± 166.1	388.8 ± 188.8	455.0 ± 263.2	635.9 ± 448.9	846.1 ± 514.1	1053.2 ± 545.3	1035.1 ± 544.3
Total flavonoids[b]	212.2 ± 151.7	312.1 ± 170.3	355.4 ± 230.9	433.8 ± 335.1	568.3 ± 398.2	714.5 ± 415.2	716.2 ± 404.9
Flavan-3-ols	123.7 ± 116	200.5 ± 137.2	234.4 ± 180.3	280.3 ± 245	379.4 ± 294.0	475.6 ± 304.7	483.3 ± 292.9
Flavonols	10.9 ± 8.3	14.3 ± 11	20.2 ± 18.4	39.6 ± 35.5	57.6 ± 43.5	74.4 ± 46.3	73.2 ± 44.2
Flavanones	16.6 ± 29.8	26.5 ± 37.9	29.8 ± 50	23.6 ± 53.7	17.9 ± 36.9	21.0 ± 40.5	16.0 ± 30.8
Flavones	15.8 ± 11.5	22.1 ± 14.7	23.1 ± 17.6	23.0 ± 19.8	24.1 ± 18.5	26.4 ± 19.1	24.9 ± 18
Isoflavones	3.7 ± 13.6	4.1 ± 8.6	3.9 ± 8.9	4.2 ± 7.7	5.2 ± 11.1	5.5 ± 10.2	5.7 ± 10.3
Anthocyanins	38.5 ± 55.4	40 ± 53.8	32.6 ± 61.6	35.7 ± 94.4	36.4 ± 70.4	45.3 ± 76.4	42.2 ± 58.3
Theaflavins	1.5 ± 5.3	2.7 ± 7.4	9.6 ± 18.2	26.6 ± 36.8	47.2 ± 51.6	65.7 ± 55.6	70.3 ± 54.5
Chalcones	1.6 ± 2.5	1.9 ± 3.5	1.7 ± 3.6	0.9 ± 1.9	0.6 ± 1.7	0.5 ± 1.4	0.7 ± 1.7
Total phenolic acids[c]	54.3 ± 24.8	76.5 ± 43.2	99.6 ± 63.4	201.3 ± 228.5	276.2 ± 232.6	336.7 ± 292.0	317.6 ± 297.0
Hydroxybenzoic acids	8.0 ± 9.4	11.8 ± 31.4	20.6 ± 29.4	47.4 ± 51	77.2 ± 69.4	104.6 ± 82.5	104.7 ± 71.2
Hydroxycinnamic acids	46.3 ± 20.7	64.7 ± 26.9	78.9 ± 53.7	153.6 ± 221.8	198.7 ± 225.3	231.8 ± 289.9	212.8 ± 297.1
Hydroxyphenylpropanoic acids	0.1 ± 0.4	0.1 ± 0.4	0.1 ± 0.4	0.2 ± 0.5	0.4 ± 0.7	0.3 ± 0.7	0.2 ± 0.4
Stilbenes	0.1 ± 0.2	0.1 ± 0.1	0.1 ± 0.4	0.8 ± 2.4	1.6 ± 3.8	1.9 ± 4.1	1.3 ± 3

Values are presented as mean ± SD

[a]Total (poly)phenol calculated as the sum of total flavonoids, total phenolic acids, and stilbenes

[b]Total flavonoids as the sum of flavan-3-ols, flavonols, flavanones, flavones, isoflavones, anthocyanins, theaflavins, and chalcones

[c]Total phenolic acids as the sum of hydroxybenzoic, hydroxycinnamic, and hydroxyphenylpropanoic acids

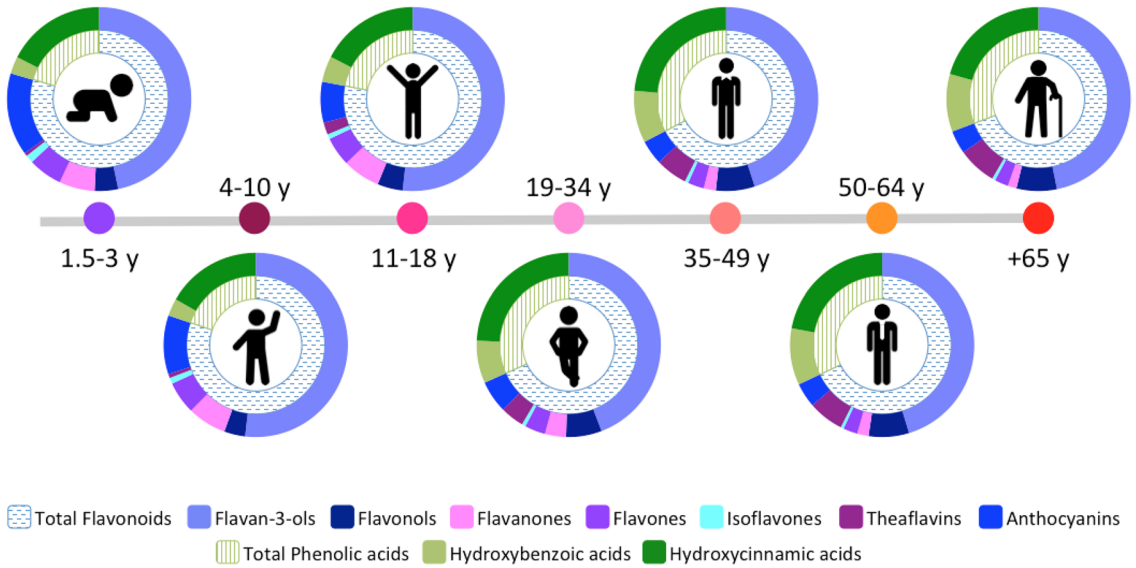

Fig. 1 Relative contribution of each class and subclass of phenolic compounds to the total (poly)phenol intake by age group. The internal circle accounts for the percentage of flavonoids and phenolic acids in the diet, while the external circle for the contribution to the phenolic intake of each phenolic subclass. Chalcones, hydroxyphenylpropanoic acids, and stilbenes were not included, since they contribute less than 1% of the total intake in all age groups

children. Although much has been reported for UK adults [10–12], there have been limited reports on the (poly)phenol intakes in children and adolescents [23]. This lack of information makes comparisons unfeasible, and thus, (poly)phenol intake for children was not compared to reported intakes in other populations.

Table 3 Intake of total (poly)phenols and (poly)phenol subclasses (mg/day) by food group and age group

	Food group								
	Total foods	Non-alcoholic beverages	Alcoholic beverages	Fruits	Vegetables	Cereals	Seeds and oils	Chocolate	Soy and derivatives
Total (poly)phenols by age group (years)[a]									
1.5–3	266.6 ± 166.1	96.9 ± 117.7	0 ± 0.1	60.1 ± 65.7	25.2 ± 16.8	27.4 ± 29	0.7 ± 3.9	32.4 ± 58.5	1.3 ± 8.7
4–10	388.8 ± 188.8	133.5 ± 119.5	0 ± 0.4	56.7 ± 75.3	40 ± 27.8	40 ± 32.7	2 ± 29.5	72.9 ± 93.8	1.1 ± 7
11–18	455.0 ± 263.2	197.8 ± 193.1	1.8 ± 11.6	31.4 ± 55.5	49.4 ± 34.4	42 ± 39	1.5 ± 12.6	87.5 ± 123.4	0.8 ± 8.7
19–34	635.9 ± 448.9	380.5 ± 383	21.3 ± 63.6	37.1 ± 66.6	61.7 ± 52.5	37 ± 33.6	2.3 ± 9.8	68.1 ± 109.6	0.6 ± 6
35–49	846.1 ± 514.1	563.4 ± 449.5	42.1 ± 101	52.6 ± 85.5	60.5 ± 44.3	38.6 ± 33.2	3.2 ± 15.1	61.3 ± 108.5	1.7 ± 10.8
50–64	1053.2 ± 545.3	738.1 ± 487.2	48.5 ± 108.7	82.6 ± 119.9	65 ± 44	41.7 ± 34.8	6.4 ± 42.4	46.2 ± 89.1	1.5 ± 7.8
65+	1035.1 ± 544.3	746.1 ± 485	32 ± 81.1	95.2 ± 119.2	58.4 ± 35.4	38.6 ± 31.4	4.2 ± 15	39.2 ± 76.7	1.8 ± 9.6
Total flavonoids by age group (years)[b]									
1.5–3	212.2 ± 151.7	63.5 ± 90.6	0.0 ± 0.1	35.0 ± 37.6	7.3 ± 9.9	18.2 ± 22.4	0.3 ± 2.8	31.6 ± 57	1.3 ± 8.7
4–10	312.1 ± 170.3	93.8 ± 89.3	0.0 ± 0.2	32.0 ± 42.6	11.2 ± 18.7	29 ± 27.4	0.4 ± 2.6	71.0 ± 91.6	1.1 ± 6.9
11–18	355.4 ± 230.9	141.9 ± 146.5	0.7 ± 5.9	17.1 ± 30.3	13.9 ± 23	29.1 ± 31.1	0.5 ± 3.8	85.2 ± 120.5	0.8 ± 8.3
19–34	433.8 ± 335.1	235.9 ± 260.3	11.1 ± 39.3	17.7 ± 30.9	22.7 ± 43.7	22.8 ± 22.4	1.4 ± 7.3	66.5 ± 107.2	0.6 ± 5.9
35–49	568.3 ± 398.2	360 ± 343.3	23.4 ± 63.3	25.1 ± 40.2	21.8 ± 33.1	22.9 ± 20.4	1.2 ± 6.5	59.9 ± 106.3	1.6 ± 10.1
50–64	714.5 ± 415.2	491.4 ± 366.8	27.8 ± 68.2	37.5 ± 57.2	22.9 ± 31.9	24.8 ± 20.3	2.5 ± 12.2	45.0 ± 87.1	1.4 ± 7.7
65+	716.2 ± 404.9	515.8 ± 363.6	19 ± 51	44.4 ± 61.9	17.4 ± 24	22.7 ± 18.4	1.9 ± 8.3	38.2 ± 74.7	1.8 ± 9.5
Flavan-3-ols by age group (years)									
1.5–3	123.7 ± 116.0	40.0 ± 77.6	0 0.0 ± 0.1	32.0 ± 33.9	1.1 ± 6.8	4.9 ± 18.7	0.3 ± 2.7	31.3 ± 56.5	0.0 ± 0.9
4–10	200.5 ± 137.2	55.8 ± 70.4	0.0 ± 0.2	29.3 ± 40	2.7 ± 14.5	11.2 ± 23.3	0.4 ± 2.4	70.6 ± 91.2	0.1 ± 1.4
11–18	234.4 ± 180.3	88.3 ± 109.4	0.6 ± 4.9	15.5 ± 28.4	3.7 ± 17.8	10.7 ± 26	0.5 ± 3.6	84.6 ± 119.9	–
19–34	280.3 ± 245.0	160.5 ± 192.1	9.0 ± 32.4	15.7 ± 28.4	7.6 ± 35.6	3.3 ± 12.5	1.3 ± 7.1	66.1 ± 106.7	–
35–49	379.4 ± 294.0	255.9 ± 253.5	19.0 ± 52.3	22.1 ± 37.1	6.6 ± 25.4	1.7 ± 7.2	1.1 ± 6.1	59.4 ± 105.7	–
50–64	475.6 ± 304.7	351.2 ± 272.6	22.6 ± 56.3	33.2 ± 53.5	6.6 ± 23.8	1.5 ± 4.9	2.4 ± 12	44.7 ± 86.7	0.1 ± 1.6
65+	483.3 ± 292.9	373.9 ± 270	15.5 ± 42.1	40 ± 58.5	3.7 ± 17.7	1.1 ± 3.2	1.7 ± 7.7	37.8 ± 74.1	–
Flavonols by age group (years)									
1.5–3	10.9 ± 8.3	3.3 ± 5.1	–	1.8 ± 2.5	5.6 ± 6.2	0.1 ± 0.4	0 ± 0.3	0.0 ± 0.2	–
4–10	14.3 ± 11	4.7 ± 6.4	–	1.8 ± 2.8	7.4 ± 8.4	0.1 ± 0.6	0 ± 0.3	0.0 ± 0.3	–
11–18	20.2 ± 18.4	10.1 ± 14.4	0.1 ± 1	1 ± 2.1	8.5 ± 10.5	0.2 ± 0.8	0 ± 0.5	0.1 ± 0.5	–
19–34	39.6 ± 35.5	23.1 ± 28.8	1.8 ± 6.4	1.4 ± 2.7	12.6 ± 16.6	0.4 ± 1.4	0.1 ± 0.5	0.1 ± 0.7	–
35–49	57.6 ± 43.5	38.3 ± 39.5	3.8 ± 10.2	2 ± 3.8	12.9 ± 14.6	0.3 ± 1	0.1 ± 0.7	0.1 ± 0.7	–
50–64	74.4 ± 46.3	52.8 ± 42.2	4.5 ± 11	2.9 ± 4.9	13.7 ± 15.5	0.2 ± 0.7	0.1 ± 0.8	0.1 ± 0.5	0 ± 0.1
65+	73.2 ± 44.2	55.6 ± 41.7	3.1 ± 8.2	2.9 ± 3.9	11.1 ± 12.5	0.1 ± 0.4	0.2 ± 0.9	0.1 ± 0.5	–
Flavanones by age group (years)									
1.5–3	16.6 ± 29.8	15.6 ± 29	–	0.1 ± 0.2	0.3 ± 0.4	0.1 ± 0.1	–	–	–
4–10	26.5 ± 37.9	25.7 ± 37.9	–	0.1 ± 0.2	0.5 ± 1.2	0.1 ± 0.1	–	–	–
11–18	29.8 ± 50.0	28.8 ± 50	0.0 ± 0.1	0.0 ± 0.3	0.7 ± 1.8	0.1 ± 0.1	–	–	–
19–34	23.6 ± 53.7	22.1 ± 53.5	0.2 ± 0.6	0.1 ± 0.5	1.0 ± 1.8	0.1 ± 0.1	–	–	–
35–49	17.9 ± 36.9	16.2 ± 36.7	0.5 ± 0.9	0.1 ± 1.0	0.9 ± 1.8	0.0 ± 0.1	–	–	–
50–64	21.0 ± 40.5	19 ± 40.1	0.6 ± 1.1	0.3 ± 1.8	1.1 ± 2.4	0.0 ± 0.1	–	–	–
65+	16.0 ± 30.8	13.8 ± 30.3	0.4 ± 0.8	0.3 ± 1.7	1.4 ± 4.6	0.0 ± 0.1	–	–	–
Flavones by age group (years)									
1.5–3	15.8 ± 11.5	1.9 ± 3.5	–	0.3 ± 0.8	0.3 ± 0.4	11.5 ± 10.8	–	0.2 ± 0.8	–
4–10	22.1 ± 14.7	3.1 ± 4.5	–	0.5 ± 1.0	0.5 ± 0.7	15.2 ± 13.9	–	0.4 ± 0.8	0.0 ± 0.1
11–18	23.1 ± 17.6	3.4 ± 6.0	–	0.4 ± 1.0	0.8 ± 1.2	15.5 ± 15.7	–	0.5 ± 1.0	0.0 ± 0.1
19–34	23.0 ± 19.8	2.6 ± 6.4	–	0.5 ± 1.0	1.2 ± 3.2	16.2 ± 17.5	–	0.3 ± 0.7	0.0 ± 0.1
35–49	24.1 ± 18.5	1.8 ± 4.0	0.0 ± 0.1	0.7 ± 1.4	1.2 ± 1.7	18.0 ± 17.6	–	0.3 ± 0.7	0.0 ± 0.1
50–64	26.4 ± 19.1	2.2 ± 4.7	0.0 ± 0.1	0.8 ± 1.6	1.4 ± 1.9	19.7 ± 17.9	–	0.2 ± 0.6	0.0 ± 0.1
65+	24.9 ± 18	1.6 ± 3.6	0.0 ± 0.1	0.9 ± 1.4	1.3 ± 1.8	18.2 ± 16.9	–	0.2 ± 0.6	0.0 ± 0.1

Table 3 (continued)

	Food group								
	Total foods	Non-alcoholic beverages	Alcoholic beverages	Fruits	Vegetables	Cereals	Seeds and oils	Chocolate	Soy and derivatives
Isoflavones by age group (years)									
1.5–3	3.7 ± 13.6	0.8 ± 7.9	–	0.6 ± 8.9	0.1 ± 0.3	1.6 ± 1.4	–	–	1.2 ± 8.6
4–10	4.1 ± 8.6	0.4 ± 3.9	–	0.2 ± 3.0	0.1 ± 0.4	2.3 ± 1.9	–	–	1.0 ± 6.2
11–18	3.9 ± 8.9	0.1 ± 0.9	–	0.1 ± 0.9	0.3 ± 1.1	2.6 ± 2.7	–	–	0.8 ± 8.3
19–34	4.2 ± 7.7	0.4 ± 3.8	–	0.1 ± 1.7	0.3 ± 0.6	2.9 ± 3.0	–	0.0 ± 0.1	0.6 ± 5.9
35–49	5.2 ± 11.1	0.8 ± 5.2	–	0.2 ± 2.2	0.2 ± 1.0	2.9 ± 2.6	–	0.0 ± 0.4	1.5 ± 10.0
50–64	5.5 ± 10.2	0.8 ± 5.7	–	0.3 ± 2.5	0.2 ± 0.8	3.4 ± 4.9	–	–	1.3 ± 7.3
65+	5.7 ± 10.3	1.3 ± 7.4	–	0.1 ± 0.7	0.1 ± 0.3	3.3 ± 3.9	–	–	1.8 ± 9.5
Anthocyanins by age group (years)									
1.5–3	38.5 ± 55.4	21.9 ± 51.4	–	15.4 ± 24.9	–	0.7 ± 6.7	–	–	–
4–10	40.0 ± 53.8	23.6 ± 45.5	0.0 ± 0.1	15.5 ± 27.4	–	0.3 ± 2.8	–	0.0 ± 0.1	–
11–18	32.6 ± 61.6	22.5 ± 57.8	0.1 ± 1.6	9.2 ± 21.4	0.0 ± 0.1	0.4 ± 4.8	–	0.0 ± 0.1	–
19–34	35.7 ± 94.4	19.7 ± 87.9	2.7 ± 11.4	12.5 ± 31.8	0.0 ± 0.1	0.1 ± 0.7	–	0.0 ± 0.1	–
35–49	36.4 ± 70.4	11.9 ± 54.9	6.1 ± 18.4	17.6 ± 40.2	0.0 ± 0.5	0.6 ± 6.3	–	0.0 ± 0.1	–
50–64	45.3 ± 76.4	7.2 ± 46.4	7.4 ± 19.8	28.6 ± 54.5	0.0 ± 0.2	0.5 ± 4.3	–	0.0 ± 0.1	–
65+	42.2 ± 58.3	4.3 ± 18.1	5.2 ± 14.8	30.7 ± 49.5	0.1 ± 1.3	0.3 ± 2.6	–	0.0 ± 0.2	–
Theaflavins by age group (years)									
1.5–3	1.5 ± 5.3	1.5 ± 5.3	–	–	–	–	–	–	–
4–10	2.7 ± 7.4	2.7 ± 7.4	–	–	–	–	–	–	–
11–18	9.6 ± 18.2	9.6 ± 18.2	–	–	–	–	–	–	–
19–34	26.6 ± 36.8	26.6 ± 36.8	–	–	–	–	–	–	–
35–49	47.2 ± 51.6	47.2 ± 51.6	–	–	–	–	–	–	–
50–64	65.7 ± 55.6	65.7 ± 55.6	–	–	–	–	–	–	–
65+	70.3 ± 54.5	70.3 ± 54.5	–	–	–	–	–	–	–
Chalcones by age group (years)									
1.5–3	1.6 ± 2.5	1.3 ± 2.4	–	0.2 ± 0.4	–	–	–	–	–
4–10	1.9 ± 3.5	1.8 ± 3.5	–	0.1 ± 0.2	–	–	–	–	–
11–18	1.7 ± 3.6	1.6 ± 3.6	–	0.0 ± 0.1	–	–	–	–	–
19–34	0.9 ± 1.9	0.8 ± 1.9	–	0.0 ± 0.1	–	–	–	–	–
35–49	0.6 ± 1.7	0.5 ± 1.7	–	0.0 ± 0.2	–	–	–	–	–
50–64	0.5 ± 1.4	0.4 ± 1.4	–	0.1 ± 0.3	–	–	–	–	–
65+	0.7 ± 1.7	0.5 ± 1.7	–	0.2 ± 0.4	–	–	–	–	–
Total phenolic acids by age group (years)[c]									
1.5–3	54.3 ± 24.8	11.4 ± 13.7	–	9.7 ± 10.8	17.9 ± 11.4	8.6 ± 9.8	0.4 ± 2.4	0.8 ± 1.7	0.0 ± 0.1
4–10	76.5 ± 43.2	16.0 ± 16.8	0.0 ± 0.1	9.2 ± 12.5	28.8 ± 17.6	10.8 ± 11.9	1.6 ± 29.4	1.8 ± 2.6	0.0 ± 0.3
11–18	99.6 ± 63.4	33.4 ± 51.8	1.0 ± 5.5	5.1 ± 10.2	35.5 ± 22.8	12.5 ± 14.9	1.0 ± 11.6	2.3 ± 3.5	0.1 ± 0.6
19–34	201.3 ± 228.5	124.9 ± 219.9	6.7 ± 13.4	6.8 ± 13.2	39 ± 25.4	14.1 ± 18.2	1.0 ± 5.6	1.6 ± 2.6	0.0 ± 0.4
35–49	276.2 ± 232.6	191.5 ± 221.6	11.1 ± 18.8	9.8 ± 17.9	38.7 ± 26.9	15.1 ± 18.6	2.0 ± 12.4	1.4 ± 2.5	0.1 ± 1.6
50–64	336.7 ± 292	239.5 ± 281.2	11.6 ± 18.9	16.4 ± 29.6	42.1 ± 27.1	16.4 ± 21.2	4.0 ± 40.4	1.1 ± 2.2	0.0 ± 0.3
65+	317.6 ± 297	225.9 ± 289.2	6.6 ± 13.3	20.0 ± 29.5	40.9 ± 23.5	15.6 ± 20.6	2.3 ± 10.0	1.0 ± 2.3	0.0 ± 0.5
Hydroxybenzoic acids by age group (years)									
1.5–3	8.0 ± 9.4	3.3 ± 7.3	–	3.4 ± 5.0	0.5 ± 2.6	0.2 ± 0.4	0.1 ± 0.9	0.3 ± 0.7	–
4–10	11.8 ± 31.4	4.9 ± 9.7	–	3.3 ± 5.4	1.4 ± 7.1	0.3 ± 0.4	0.9 ± 28.7	0.6 ± 1.0	0.0 ± 0.1
11–18	20.6 ± 29.4	14.0 ± 24.0	0.6 ± 3.7	2.0 ± 5.2	2.2 ± 11.5	0.3 ± 0.6	0.4 ± 10.5	0.8 ± 1.3	0.0 ± 0.3
19–34	47.4 ± 51	36.4 ± 48.2	3.7 ± 7.6	2.5 ± 6.4	3.5 ± 14.0	0.3 ± 0.6	0.2 ± 1.7	0.6 ± 1.2	0.0 ± 0.3
35–49	77.2 ± 69.4	63.1 ± 67.1	5.8 ± 10.0	3.4 ± 10.3	3.2 ± 14.3	0.3 ± 0.8	0.6 ± 8.1	0.5 ± 1.0	0.0 ± 0.8
50–64	104.6 ± 82.5	87.6 ± 71.6	5.7 ± 9.1	5.5 ± 17.7	2.6 ± 15.1	0.4 ± 1.1	2.2 ± 39.3	0.4 ± 0.9	0.0 ± 0.3

Table 3 (continued)

	Food group								
	Total foods	Non-alcoholic beverages	Alcoholic beverages	Fruits	Vegetables	Cereals	Seeds and oils	Chocolate	Soy and derivatives
65+	104.7 ± 71.2	93.3 ± 70.7	3.1 ± 6.2	4.6 ± 9.5	1.9 ± 8.7	0.5 ± 1.4	0.8 ± 5.6	0.3 ± 0.8	–
Hydroxycinnamic acids by age group (years)									
1.5–3	46.3 ± 20.7	8.1 ± 10.0	–	6.2 ± 8.0	17.5 ± 10.6	8.4 ± 9.7	0.3 ± 2.2	0.5 ± 1.1	0.0 ± 0.1
4–10	64.7 ± 26.9	11.1 ± 12.3	0.0 ± 0.1	5.9 ± 9.5	27.5 ± 15.6	10.5 ± 11.8	0.7 ± 6.3	1.2 ± 2.0	0.0 ± 0.3
11–18	78.9 ± 53.7	19.4 ± 44.4	0.3 ± 1.8	3.1 ± 7.5	33.3 ± 19.8	12.1 ± 14.8	0.7 ± 4.4	1.5 ± 2.6	0.0 ± 0.5
19–34	153.6 ± 221.8	88.5 ± 216.1	2.9 ± 6.3	4.2 ± 9.4	35.5 ± 21.6	13.7 ± 18	0.8 ± 5.0	1.0 ± 1.8	0.0 ± 0.3
35–49	198.7 ± 225.3	128.4 ± 218.7	5.2 ± 9.4	6.3 ± 11.6	35.6 ± 22.8	14.7 ± 18.3	1.3 ± 7.7	0.9 ± 1.7	0.1 ± 1.3
50–64	231.8 ± 289.9	151.9 ± 282.4	5.7 ± 10.1	10.8 ± 21.1	39.5 ± 22.5	15.7 ± 20.9	1.7 ± 9.5	0.8 ± 1.5	0.0 ± 0.2
65+	212.8 ± 297.1	132.6 ± 291.9	3.5 ± 7.3	15.4 ± 26.5	39.0 ± 22.3	15 ± 19.9	1.5 ± 8.1	0.7 ± 1.7	0.0 ± 0.5
Hydroxyphenylpropanoic acids by age group (years)									
1.5–3	0.1 ± 0.4	–	–	0.1 ± 0.4					
4–10	0.1 ± 0.4	–	–	0.1 ± 0.4	–	–	–	–	–
11–18	0.1 ± 0.4	–	0.0 ± 0.2	0.0 ± 0.3	–	–	–	–	–
19–34	0.2 ± 0.5	–	0.1 ± 0.3	0.1 ± 0.4	–	0.0 ± 0.1	–	–	–
35–49	0.4 ± 0.7	–	0.2 ± 0.4	0.2 ± 0.6	–	–	–	–	–
50–64	0.3 ± 0.7	–	0.2 ± 0.3	0.1 ± 0.7	–	–	–	–	–
65+	0.2 ± 0.4	–	0.1 ± 0.2	0.1 ± 0.4	–	–	–	–	–
Stilbenes by age group (years)									
1.5–3	0.1 ± 0.2	0.0 ± 0.1	–	0.1 ± 0.1	–	–	–	–	–
4–10	0.1 ± 0.1	0.0 ± 0.1	–	0.1 ± 0.1	–	–	–	–	–
11–18	0.1 ± 0.4	0.0 ± 0.1	0.0 ± 0.4	0.0 ± 0.1	–	–	–	–	–
19–34	0.8 ± 2.4	0.0 ± 0.1	0.7 ± 2.4	0.0 ± 0.1	–	–	–	–	–
35–49	1.6 ± 3.8	0.0 ± 0.1	1.5 ± 3.8	0.1 ± 0.2	–	–	–	–	–
50–64	1.9 ± 4.1	0.0 ± 0.2	1.8 ± 4.1	0.1 ± 0.2	–	–	–	–	–
65 +	1.3 ± 3.0	0.0 ± 0.2	1.2 ± 3.0	0.1 ± 0.2	–	–	–	–	-

Values are presented as mean ± SD

[a]Total (poly)phenol calculated as the sum of total flavonoids, total phenolic acids, and stilbenes

[b]Total flavonoids as the sum of flavan-3-ols, flavonols, flavanones, flavones, isoflavones, anthocyanins, theaflavins, and chalcones

[c]Total phenolic acids as the sum of hydroxybenzoic, hydroxycinnamic, and hydroxyphenylpropanoic acids

Previously reported total (poly)phenol intake in the UK population was from the EPIC study, where intake was 1521 mg/day in health-conscious adults and about 1700 mg/day for the general population aged 35–74 years [10]. The total phenolic intakes in this NDNS RP population were substantially lower in comparison with the UK population in the EPIC cohort. On the contrary, our findings were similar to those reported for other non-Mediterranean countries included in the EPIC study, where mean (poly)phenol intake was 1284 mg/day [10]. Our results in adults were also similar to the mean intake in adults aged 45–60 years in the SU.VI.MAX cohort in France (1193 ± 510 mg/day compared to 846 ± 514 and 1053 ± 545 mg/day in the equivalent age groups in our study). Similarly, total (poly)phenol intake was 1741 ± 630 mg/day in adults aged 45–69 years in a Polish cohort [24], 1199 ± 694 mg/day in adults aged 60 years and over in Brazil [25], and 1492 ± 665 mg/day in Japanese adults aged 52–89 years [26], which was much higher than intakes in the equivalent age groups in the NDNS RP population. However, NDNS RP phenolic intakes were higher than reported intakes in adults with type 2 diabetes aged 50–75 years in Italy (683 ± 6 mg/day) [27], in adults aged 55–80 years at high risk of CVD in Spain (820 ± 323 mg/day) [28], and 863 ± 415 mg/day in Finnish adults aged 25–64 years [29]. Besides the intrinsic population differences, dietary tools and databases used may account for this heterogeneity. Regarding individual differences, it should be noted that total (poly)phenol intakes were higher in males than females; however, energy-adjusted intakes showed that dietary consumption of phenolic compounds was higher in females across all age groups except in children aged 1.5–3 years. This is in line with the previous research, suggesting that the higher

Table 4 Most consumed individual (poly)phenols (mg/day, mean ± SD) and their three highest food sources (% contribution to phenolic class) by age group

(Poly)phenol	(Poly)phenol subclass	Three highest food contributors						
		1.5–3 years	4–10 years	11–18 years	19–34 years	35–49 years	50–64 years	65 + years
N		819	1772	2045	1067	1421	1174	1076
Proanthocyanidin polymers (> 10 mers)	Flavan-3-ols	44.8 ± 43.9	71.9 ± 51.2	71.3 ± 61.9	55.4 ± 58.6	53.1 ± 56.2	54.4 ± 54.8	49.6 ± 49.2
		Fruit excluding apples, pears, citrus and bananas (23%)	Chocolate (20%)	Chocolate (28%)	Chocolate (27%)	Chocolate (25%)	Chocolate (17%)	Fruit excluding apples, pears, citrus and bananas (18%)
		Chocolate (16%)	Fruit excluding apples, pears, citrus and bananas (14%)	Biscuits (15%)	Biscuits (13%)	Fruit excluding apples, pears, citrus and bananas (14%)	Fruit excluding apples, pears, citrus and bananas (16%)	Chocolate (14%)
		Soft drinks (12%)	Biscuits (14%)	Cakes (10%)	Soft drinks (9%)	Biscuits (13%)	Biscuits (12%)	Cakes (12%)
5-Caffeoylquinic acid	Hydroxycinnamic acids	20.9 ± 11.4	30.4 ± 16	38.0 ± 25.0	60.1 ± 74.9	72.4 ± 74.5	83.2 ± 93.2	78.7 ± 102.7
		Potatoes (47%)	Potatoes (55%)	Potatoes (59%)	Potatoes (47%)	Potatoes (40%)	Potatoes (40%)	Potatoes (43%)
		Savoury snacks (10%)	Savoury snacks (12%)	Savoury snacks (11%)	Coffee (21%)	Coffee (31%)	Coffee (31%)	Coffee (26%)
		Fruit juice (8%)	Fruit juice (8%)	Fruit juice (5%)	Savoury snacks (7%)	Savoury snacks (5%)	Savoury snacks (3%)	Savoury snacks (4%)
Gallocatechin	Flavan-3-ols	1.7 ± 5.9	3.0 ± 8.3	10.9 ± 20.5	30.2 ± 41.4	53.3 ± 57.9	74.3 ± 62.3	79.4 ± 61.2
		Fruit excluding apples, pears, citrus and bananas (31%)	Fruit excluding apples, pears, citrus and bananas (31%)	Tea (48%)	Tea (74%)	Tea (78%)	Tea (86%)	Tea (89%)
		Tea (16%)	Tea (21%)	Fruit excluding apples, pears, citrus and bananas (12%)	Fruit excluding apples, pears, citrus and bananas (4%)	Wine (8%)	Wine (6%)	Wine (5%)
		Puddings (14%)	Yogurt (11%)	Soft drinks (9%)	Wine (4%)	Fruit excluding apples, pears, citrus and bananas (5%)	Fruit excluding apples, pears, citrus and bananas (3%)	Fruit excluding apples, pears, citrus and bananas (2%)
Proanthocyanidin oligomers (04–06 mers)	Flavan-3-ols	23.2 ± 26.3	39.8 ± 30.3	40.7 ± 38.1	30.6 ± 33.6	29.3 ± 32.9	28.6 ± 30.8	26.9 ± 28.4
		Chocolate (19%)	Chocolate (22%)	Chocolate (29%)	Chocolate (28%)	Chocolate (25%)	Chocolate (18%)	Chocolate (15%)
		Fruit excluding apples, pears, citrus and bananas (15%)	Biscuits (16%)	Biscuits (16%)	Biscuits (13%)	Biscuits (13%)	Fruit excluding apples, pears, citrus and bananas (12%)	Fruit excluding apples, pears, citrus and bananas (14%)
		Biscuits (11%)	Cakes (12%)	Cakes (10%)	Cakes (8%)	Fruit excluding apples, pears, citrus and bananas (10%)	Biscuits (11%)	Biscuits (11%)
5-Galloylquinic acid	Hydroxybenzoic acids	1.4 ± 4.9	2.5 ± 6.8	9.2 ± 17.1	25.6 ± 34.7	44.8 ± 47.9	62.5 ± 51.2	66.2 ± 50.4
		Soft drinks (28%)	Soft drinks (28%)	Tea (47%)	Tea (74%)	Tea (81%)	Tea (87%)	Tea (90%)
		Fruit excluding apples, pears, citrus and bananas (17%)	Tea (21%)	Soft drinks (23%)	Soft drinks (11%)	Yogurt (4%)	Yogurt (4%)	Cakes (3%)
		Tea (16%)	Fruit excluding apples, pears, citrus and bananas (19%)	Fruit (7%)	Yogurt (3%)	Soft drinks (4%)	Fruit excluding apples, pears, citrus and bananas (3%)	Yogurt (2%)

Table 4 (continued)

(Poly)phenol	(Poly)phenol subclass	Three highest food contributors						
		1.5–3 years	4–10 years	11–18 years	19–34 years	35–49 years	50–64 years	65 + years
Epigallocatechin 3-*O*-gallate	Flavan-3-ols	1.1 ± 3.9 Tea (41%) Fruit excluding apples, pears, citrus and bananas (19%) Breakfast cereals (13%)	2 ± 5.4 Tea (41%) Jams and preserves (19%) Fruit excluding apples, pears, citrus and bananas (14%)	7.8 ± 15.3 Tea (68%) Chocolate (9%) Jams and preserves (7%)	22.1 ± 34.1 Tea (86%) Chocolate (4%) Breakfast cereals (3%)	37.3 ± 41.2 Tea (90%) Breakfast cereals (3%) Chocolate (2%)	52.2 ± 45 Tea (93%) Breakfast cereals (2%) Fruit excluding apples, pears, citrus and bananas (1%)	54.0 ± 42.2 Tea (95%) Breakfast cereals (2%) Nuts and Seeds (1%)
Proanthocyanidin oligomers (07–10 mers)	Flavan-3-ols	15.7 ± 17.1 Fruit excluding apples, pears, citrus and bananas (19%) Chocolate (18%) Biscuits (11%)	26.3 ± 19.7 Chocolate (22%) Biscuits (15%) Cakes (2%)	26.5 ± 24.2 Chocolate (30%) Biscuits (17%) Cakes (10%)	20.0 ± 21.8 Chocolate (29%) Biscuits (14%) Cakes (8%)	19.3 ± 21 Chocolate (26%) Biscuits (14%) Fruit excluding apples, pears, citrus and bananas (12%)	19.3 ± 20.2 Chocolate (19%) Fruit excluding apples, pears, citrus and bananas (14%) Biscuits (12%)	17.9 ± 18.4 Fruit excluding apples, pears, citrus and bananas (16%) Chocolate (15%) Biscuits (12%)
4-Caffeoylquinic acid	Hydroxycinnamic acids	0.7 ± 1.3 Tomatoes (21%) Beans and pulses (18%) Tea (10%)	0.9 ± 1.2 Tomatoes (21%) Beans and pulses (17%) Tea (13%)	3.7 ± 12.1 Tea (25%) Tomatoes (14%) Sauces and condiments (11%)	24.9 ± 57.8 Coffee (39%) Tea (32%) Tomatoes (9%)	37.7 ± 57.8 Coffee (52%) Tea (35%) Tomatoes (5%)	44.8 ± 74.5 Coffee (53%) Tea (37%) Tomatoes (4%)	39.5 ± 73.4 Coffee (47%) Tea (42%) Tomatoes (3%)
Epigallocatechin	Flavan-3-ols	0.9 ± 3.0 Fruit excluding apples, pears, citrus and bananas (26%) Tea (16%) Bananas (10%)	1.6 ± 4.3 Fruit excluding apples, pears, citrus and bananas (23%) Tea (20%) Jams and preserves (9%)	6.1 ± 11.8 Tea (42%) Soft drinks (11%) Fruit excluding apples, pears, citrus and bananas (9%)	17.4 ± 26 Tea (66%) Soft drinks (5%) Bananas (4%)	29.3 ± 32.0 Tea (74%) Fruit excluding apples, pears, citrus and bananas (5%) Wine (4%)	41.1 ± 34.8 Tea (83%) Wine (3%) Fruit excluding apples, pears, citrus and bananas (3%)	42.7 ± 32.9 Tea (86%) Wine (3%) Fruit excluding apples, pears, citrus and bananas (2%)
Epicatechin 3-*O*-gallate	Flavan-3-ols	1.0 ± 3.1 Fruit excluding apples, pears, citrus and bananas (41%) Tea (16%) Soft drinks (13%)	1.7 ± 4.3 Fruit excluding apples, pears, citrus and bananas (34%) Tea (20%) Soft drinks (17%)	6.0 ± 10.9 Tea (44%) Soft drinks (19%) Fruit excluding apples, pears, citrus and bananas (15%)	16.6 ± 22.3 Tea (70%) Soft drinks (8%) Fruit excluding apples, pears, citrus and bananas (7%)	28.9 ± 30.5 Tea (75%) Fruit excluding apples, pears, citrus and bananas (8%) Wine (7%)	40.3 ± 32.5 Tea (83%) Wine (5%) Fruit excluding apples, pears, citrus and bananas (5%)	42.5 ± 32 Tea (87%) Wine (4%) Fruit excluding apples, pears, citrus and bananas (3%)
Epicatechin	Flavan-3-ols	7.0 ± 7.0 Fruit juice (16%) Chocolate (13%) Soft drinks (11%)	11.0 ± 8.7 Chocolate (17%) Fruit juice (15%) Biscuits (11%)	13.3 ± 10.9 Chocolate (20%) Tea (19%) Biscuits (10%)	16.5 ± 15.3 Tea (40%) Chocolate (15%) Biscuits (6%)	23.0 ± 18.3 Tea (53%) Chocolate (10%) Wine (8%)	29.3 ± 19.2 Tea (63%) Wine (8%) Chocolate (6%)	29.8 ± 18.5 Tea (67%) Wine (5%) Chocolate (5%)

Table 4 (continued)

(Poly)phenol	(Poly)phenol subclass	Three highest food contributors						
		1.5–3 years	4–10 years	11–18 years	19–34 years	35–49 years	50–64 years	65 + years
3-Caffeoylquinic acid	Hydroxycinnamic acids	1.9 ± 4.3 Soft drinks (32%) Leafy vegetables (17%) Fruit excluding apples, pears, citrus and bananas (11%)	2.2 ± 5.1 Soft drinks (32%) Leafy vegetables (18%) Fruit excluding apples, pears, citrus and bananas (11%)	3.9 ± 11.5 Soft drinks (25%) Tea (18%) Leafy vegetables (13%)	22.1 ± 51.2 Coffee (41%) Tea (23%) Soft drinks (10%)	33.3 ± 52.6 Coffee (56%) Tea (23%) Leafy vegetables (5%)	40.5 ± 69.8 Coffee (57%) Tea (23%) Fruit excluding apples, pears, citrus and bananas (7%)	37.2 ± 68.3 Coffee (51%) Tea (22%) Fruit excluding apples, pears, citrus and bananas (13%)
Procyanidin dimer B1	Flavan-3-ols	3.4 ± 3.8 Chocolate (17%) Biscuits (12%) Fruit excluding apples, pears, citrus and bananas (11%)	5.7 ± 4.5 Chocolate (20%) Biscuits (14%) Cakes (11%)	7.9 ± 6.9 Tea (23%) Chocolate (22%) Biscuits (13%)	11.8 ± 11.7 Tea (46%) Chocolate (16%) Biscuits (6%)	18.2 ± 16.2 Tea (58%) Chocolate (10%) Wine (7%)	24 ± 17.1 Tea (68%) Wine (7%) Chocolate (6%)	24.9 ± 16.7 Tea (72%) Wine (5%) Chocolate (4%)
Catechin	Flavan-3-ols	4.5 ± 3.9 Fruit excluding apples, pears, citrus and bananas (15%) Bananas (14%) Chocolate (12%)	6.9 ± 4.5 Chocolate (16%) Fruit excluding apples, pears, citrus and bananas (11%) Biscuits (11%)	8.1 ± 6.1 Chocolate (20%) Tea (18%) Biscuits (11%)	10.9 ± 9.1 Tea (36%) Chocolate (14%) Wine (7%)	16.0 ± 12.4 Tea (47%) Wine (11%) Chocolate (9%)	20.3 ± 12.9 Tea (56%) Wine (11%) Chocolate (5%)	20.0 ± 11.9 Tea (62%) Wine (8%) Fruit excluding apples, pears, citrus and bananas (6%)
Apigenin-6,8-*C*-galactoside-*C*-arabinoside	Flavones	8.2 ± 6.6 Breakfast cereals (34%) Bread (30%) Biscuits (13%)	11.3 ± 8.4 Bread (34%) Breakfast cereals (30%) Biscuits (10%)	11.6 ± 9.8 Bread (36%) Breakfast cereals (24%) Biscuits (9%)	11.7 ± 10.8 Bread (41%) Breakfast cereals (19%) Biscuits (7%)	12.8 ± 10.8 Bread (46%) Breakfast cereals (22%) Biscuits (8%)	13.9 ± 10.9 Bread (46%) Breakfast cereals (23%) Biscuits (8%)	13.5 ± 10.5 Bread (44%) Breakfast cereals (23%) Biscuits (10%)
Catechin-3-*O*-gallate	Flavan-3-ols	0.6 ± 2 Tea (95%)	1.0 ± 2.8 Tea (96%)	3.7 ± 6.9 Tea (98%)	10.1 ± 14 Tea (98%)	18.0 ± 19.6 Tea (99%)	25 ± 21.2 Tea (100%)	26.8 ± 20.7 Tea (100%)
Procyanidin dimer B2	Flavan-3-ols	5.0 ± 5.5 Fruit juice (18%) Soft drinks (14%) Chocolate (12%)	7.0 ± 7.1 Fruit juice (18%) Chocolate (15%) Biscuits (10%)	8.1 ± 7.9 Tea (20%) Chocolate (18%) Fruit juice (12%)	9.8 ± 9.0 Tea (42%) Chocolate (14%) Soft drinks (7%)	13.9 ± 11.7 Tea (54%) Chocolate (10%) Wine (8%)	17.8 ± 12.3 Tea (64%) Wine (9%) Chocolate (6%)	18.7 ± 11.9 Tea (68%) Wine (6%) Chocolate (4%)
Hesperidin	Flavanones	8.8 ± 16.2 Soft drinks (40%) Fruit juice (31%) Puddings (5%)	14.1 ± 20.6 Fruit juice (40%) Soft drinks (39%) Sauces and condiments (4%)	15.7 ± 27.1 Soft drinks (39%) Fruit juice (37%) Sauces and condiments (7%)	12.1 ± 29.1 Fruit juice (34%) Soft drinks (31%) Sauces and condiments (12%)	8.4 ± 18.4 Fruit juice (31%) Soft drinks (24%) Sauces and condiments (14%)	10.1 ± 21.3 Fruit juice (36%) Soft drinks (18%) Sauces and condiments (13%)	7.4 ± 16.2 Fruit juice (29%) Soft drinks (16%) Sauces and condiments (11%)

Table 4 (continued)

(Poly)phenol	(Poly)phenol subclass	Three highest food contributors						
		1.5–3 years	4–10 years	11–18 years	19–34 years	35–49 years	50–64 years	65 + years
Procyanidin trimer C1	Flavan-3-ols	10.6 ± 17.1	14.2 ± 23.9	13.1 ± 24.5	8.7 ± 13.2	8.2 ± 12.2	9.0 ± 10.5	9.9 ± 12.4
		Soft drinks (24%)	Fruit juice (25%)	Soft drinks (23%)	Tea (32%)	Tea (46%)	Tea (55%)	Tea (57%)
		Fruit juice (24%)	Soft drinks (21%)	Fruit juice (17%)	Soft drinks (16%)	Chocolate (8%)	Wine (9%)	Fruit juice (7%)
		Apples (8%)	Chocolate (9%)	Tea (14%)	Fruit juice (12%)	Soft drinks (8%)	Fruit juice (6%)	Wine (7%)
Theaflavin-3,3-*O*-digallate	Flavan-3-ols	0.5 ± 1.7	0.9 ± 2.4	3.1 ± 6.0	8.7 ± 12.1	15.5 ± 16.9	21.5 ± 18.2	23.0 ± 17.9
		Tea (95%)	Tea (99%)	Tea (99%)	Tea (99%)	Tea (100%)	Tea (100%)	Tea (100%)
		Soft drinks (5%)	Soft drinks (1%)	Soft drinks (1%)	Soft drinks (1%)			

intakes in men are due to higher food intake, whereas the higher intakes in women are due to higher consumption of (poly)phenol-rich foods [24, 29, 30].

Flavonoids were the highest consumed (poly)phenol subclass, with flavan-3-ols contributing the most to this intake. Intake of flavonoids (anthocyanins, flavonols, flavan-3-ols, flavanones, and flavones) in the UK, estimated using Food Balance Sheets from the Food and Agricultural Organisation, was 182 mg/day; however, there are no population descriptors reported [31], and although it is not possible to compare directly, intake of flavonoids across all age groups in our analysis was higher. On the contrary, flavonoid intake for the UK-EPIC general population aged 35–74 years was higher, about 1020 mg/day [10]. Total intake of flavonoids in the NDNS survey conducted in 2000/01 (1724 adults aged 18–64 years) was similar to the data reported here for the NDNS RP (434–715 mg/day compared to 506 mg/day) [12]. Intakes of flavonoid subclasses were higher in the NDNS RP than those previously reported using data from the NDNS of adults survey of 2000/01: anthocyanins (36–45 mg/day compared to 16 mg/day), flavan-3-ols (280–465 mg/day compared to 28 mg/day), flavanones (18–24 mg/day compared to 9 mg/day), and flavones (23–24 mg/day compared to 2 mg/day) [12]. Intake of theaflavins was substantially lower (26.6–65.7 mg/day) compared to 351.8 mg/day reported in the UK from the NDNS survey 2000/01; however, thearubigins (oligomeric and polymeric forms of theaflavins) were also included in the previous estimate [32]. Intake of theaflavins in the EPIC general and health-conscious UK population (29.3 mg/day and 27.4 mg/day in men and 25.3 mg/day and 21.2 mg/day in women, respectively) was comparable or lower than those in the NDNS RP (26.6–65.7 mg/day) [11]. Intake of phenolic acids in the UK-EPIC general and health-conscious population (669.0 mg/day and 596.2 mg/day in men and 612.2 mg/day and 486.2 mg/day in women, respectively) was higher than intakes reported in this analysis (276.2–336.7 mg/day) [33]. Thus, previously reported intakes in the UK population are not consistent with the findings from this analysis, with some studies reporting a higher intake and others reporting lower intakes. Some of the differences could be due to differences in the methodology and in the time frame of data collection. EPIC used a single 24-h recall collected between 1992 and 2000, whereas the NDNS RP used a 4-day estimated food diary, which is likely to be more representative of habitual intake as captures some of the daily variation in intake, collected between 2008 and 2014. In addition, the NDNS RP sample is a population sample and thus more likely to be representative of the UK general population as compared to a research cohort, which was recruited from the general population in the UK but resident within certain geographical areas. The previous NDNS of adults was carried out in 2000/01 and used 7-day weighed food diaries, which is a comparable methodology

but has a greater ability to capture infrequently consumed foods. In addition, the previous studies have used a combination of the UDSA flavonoid database followed by Phenol-Explorer for missing values and then estimation based on logical zeros or similar food items and application of retention factors and recipes for calculating (poly)phenol content. The differences in the intakes may reflect food preferences in different countries. The main contributors to (poly)phenol intake were non-alcoholic beverages (tea and coffee), followed by chocolate, fruit juice, and fruit. Tea was the main source of flavonoids, whereas coffee was the main source of hydroxycinnamic acids. There was variation in contributors with age, some of which is expected. For example, young children either do not drink or drink small amounts of tea and coffee, and thus, these major sources of (poly)phenol intake only contribute small proportions to intake in this age group. For most of the flavan-3-ol monomers and dimers, wine was amongst the three highest contributors of intake only in adults aged 35 years and over. This may be partly because young adults are less likely to drink than any other age group in Great Britain, but consumption on the days they do drink tends to be higher than other age groups and are more likely to drink spirits and liquors [34]. The proportion of adults consuming alcohol increased up to 75 years after which a decline was observed [35]. Amongst men, 60% of alcohol consumed was from beer and 26% from wine, whereas in women 60% of alcohol consumed was in the form of wine and 19% from beer with smaller contributions from spirits [36].

Some interesting results related to the main sources of specific groups of phenolic compounds arose from this study. Soy-based foods are the most common sources of isoflavones [37]. However, in this population, cereals contributed more to isoflavone intake than soy products. This may be because the majority of sliced bread in the UK contain small amounts of soya flour, which is a concentrated source as compared to cooked soybeans and soy products. Bread and bread rolls have previously been shown to the main contributor to isoflavone intake in the general population in the UK (Norfolk) arm of EPIC [38]. On the other hand, potatoes were the main source of 5-caffeoylquinic acid across all age groups, with coffee being the second highest contributor in adults aged 19 years and over. This is in contrast to the previous research in other populations in which coffee is the main contributor with potatoes only contributing 9–10% [24, 28, 30]. In the UK, sources of 5-caffeoylquinic acid were previously only reported in the health-conscious group of EPIC, in whom coffee contributed 78% and potatoes 7%. In the NDNS RP population, 63% of adults reported consuming coffee and 92% reported consuming potatoes, which may explain the fact that potatoes are the main source of phenolic acids in the UK diet. The contribution of biscuits to (poly)phenol intake is primarily from ingredients such as cocoa powder and this highlights the contribution of processed and packaged foods to dietary (poly)phenol intakes.

The large sample size of NDNS and the use of Phenol-Explorer, the most comprehensive database of (poly)phenol content, together with an ad hoc literature search to fill the gaps of Phenol-Explorer with regard to some UK food products, are the strengths of this analysis. It is possible that phenolic intake from non-alcoholic beverages such as coffee and herbal tea may be underestimated due to lack of information on strength, brewing method, and type of beans in the case of coffee, and details on content in the case on herbal tea [39]. Underestimation of dietary intake of (poly)phenols could also originate from the fact that lignans and other minor (poly)phenols were not taken into account, although their contribution to the total dietary intake of phenolic compounds is rather scarce in European populations (< 1%) [10, 24, 28, 30]. Moreover, Phenol-Explorer does not account for all non-extractable (poly)phenols in plant foods [40], and thus, total intake may have been even higher. On the other hand, a degree of reactivity to food record keeping [41] and other dietary misreporting cannot be excluded, especially for the older children and young adults. Overall, this work provides an updated and comprehensive assessment of the dietary intake of (poly)phenolic compounds for the UK population. Of note, not only adults but also children and adolescents were taken into account. Insights related to children and adolescents are novel due to the lack of information on this regard. Undeniably, further reports on (poly) phenol intake for these age groups are needed. This would help to collect dietary data supporting the development of nutritional guidelines including phenolic compounds [42], as well as to make the putative preventive benefits of phenolic-rich diets available along lifespan. Increasing knowledge on this key topic would help in the development of educational and health policies targeting the dietary habits of children and adolescents. The information collected may also be useful for future studies on the associations between phenolic intake and prevalence of non-communicable chronic diseases within the NDNS RP population.

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Author contributions NZ conducted research, analyzed and interpreted data, performed statistical analysis, and wrote the paper; AR conducted research, assisted in data analysis and interpretation, and contributed to writing the manuscript; DDR designed research, contributed to manuscript revision and had primary responsibility for final content; BA and SN conducted research and provided critical review of the manuscript; PP, FS, and FB provided critical review of the manuscript; SR designed research, provided critical review of the manuscript, and had primary responsibility for final content; and PM designed research, interpreted the results, contributed to manuscript revision, and had primary responsibility for final content. All authors read and approved the final manuscript.

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Compliance with ethical standards

Conflict of interest Authors declare no conflict of interest.

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