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Dietary flavonoids among children and adolescents in the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study: intake, food sources and trends from 1985 until 2016

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Abstract

Flavonoids are suggested to reduce disease risk. Since dietary habits are acquired during early life, describing age and time trends of flavonoid intake and major food sources are important for monitoring and disease prevention in later life. We aimed to describe total flavonoid intake and food sources and to investigate age and time trends of flavonoid intake in 3–18-year-olds, from the Dortmund Nutritional and Anthropometric Longitudinally Designed study from 1985 to 2016. Intake was assessed annually using 3-d weighed food records (WFR). Flavonoid values were assigned using the United States Department of Agriculture database. Foods contributing to intake were determined. Age and time trends in total flavonoid and isoflavone density were analysed by sex with PROC MIXED. In total, 1312 children completed 10 758 WFR. Across all ages, daily mean total flavonoid density was lower in boys compared with girls (134 *v.* 146 mg/4184 kJ) and no difference in median isoflavone density (0·04 mg/4184 kJ per d) was found. The top five foods contributing to total flavonoid intake were apple with peel (15·0/17·1 %), strawberries (5·9/6·1 %), chocolate spread (3·9/3·5 %), orange juice (3·5/3·4 %) and pasta (3·5/3·4 %) for boys and girls, respectively. Overall, in boys, total flavonoid density decreased over the course of age and time. In girls, there was no association with age or time. In both sexes, isoflavone density followed a U-shaped age trend with no change over time. From a public health perspective, the overall observed downwards trend of flavonoid intake in boys deserves attention. Future initiatives should be tailored at maintaining a high flavonoid density as children age, specifically among boys.

Key words: **Flavonoids: Children: Dietary intake: Isoflavones: Epidemiology**

Recently, several meta-analyses showed an inverse association between dietary flavonoid intake and all-cause mortality, CVD[1], type 2 diabetes[2] and cancer[3]. Flavonoids are a group of polyphenols that are widely dispersed in plant-based foods. They have been shown to possess a wide range of disease-preventive properties including anti-inflammatory and antioxidant properties[4]. The subgroup of isoflavones differs from the other flavonoid subgroups because of their ability to beneficially influence hormone-related diseases by mimicking the hormone oestrogen[5]. Furthermore, isoflavones are mainly present in soya-based foods, which are becoming of significant importance to Western populations since soya flour and soya protein are increasingly used in processed foods such as bakery products[5].

The mean total flavonoid and isoflavone intake in European adults in the European Prospective Investigation into Nutrition and Cancer (EPIC) was estimated at 500 and 1 mg/d, respectively[6]. However, data on flavonoid intake in childhood and adolescence are scarce. In Australian children and adolescents, the mean flavonoid intake ranged between 24 and 66 mg/d for 2–3- and 16–18-year-olds, respectively[7]. Spanish children and young adults (aged 2–24 years) had an estimated mean total flavonoid and isoflavone intake of 70·7 and 0·1 mg/d, respectively[8]. Both studies used 24-h recall data. Flavonoid intake in Chinese female adolescents (12–18 years) was 20 mg/d and did not vary between assessment with a FFQ or 24-h recall[9]. Mean total flavonoid intake for adolescents

Abbreviations: DONALD, Dortmund Nutritional and Anthropometric Longitudinally Designed; USDA, United States Department of Agriculture; WFR, weighed food records.

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(12·5–17·5 years) in the Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA) study was estimated at 120 mg/4184 kJ per d using two non-consecutive 24-h recalls[10]. Since dietary habits develop during childhood and adolescence, they are considered very important for shaping lifelong dietary habits and the prevention of chronic diseases later in life[11,12]. However, the few studies that described flavonoid intake in children and adolescents are limited to cross-sectional analysis[7,8], a certain age group[9], girls[9], or in the case of isoflavones to Asian populations[13]. Thus, age and time trends in flavonoid and isoflavone intake and its main food sources can only be monitored using a longitudinal open cohort study design.

The aim of this study was therefore to (1) describe habitual flavonoid and isoflavone intake in children and adolescents; (2) determine the main food sources and (3) study age and time trends of flavonoid and isoflavone density. The study was conducted among healthy children and adolescents aged 3–18 years, from the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study with data collected between 1985 and 2016.

Methods

Study population

The DONALD study is an ongoing, longitudinal (open cohort) study that started in 1985. Study details have been published elsewhere[14]. Briefly, each year approximately thirty to forty new participants are enrolled into the study and followed from infancy into adulthood. Infants are recruited in the city of Dortmund and surrounding communities via personal contacts, maternity wards or paediatric practices. Detailed data on diet, growth, development, metabolism and health status are collected at regular time intervals. All examinations and assessments are made with parental and/or participant's consent. The DONALD study, which is exclusively observational, has been approved by the Ethics Committee of Bonn University. The present analysis includes a total of 10 758 weighed food records (WFR) that were completed between 1985 and 2016 by 1312 children (49·7 % girls) from 966 families.

Dietary assessment

Three-day WFR are used to assess dietary intake annually. Parents, or children who are capable, are requested to weigh and record all consumed foods and beverages, as well as leftovers to the nearest 1 g. When weighing is not possible, semi-quantitative recording using spoons or cups is allowed. Nutrient and energy intakes were calculated using LEBTAB[15], a continuously updated in-house nutrient database. To estimate flavonoid intake, a flavonoid food composition table was compiled as an extension of the LEBTAB database so that a flavonoid value was assigned to all foods that were consumed and contain flavonoids. First, all recorded food items were broken down to the ingredient level, and ingredients were assigned flavonoid values. The three United States Department of Agriculture (USDA) databases for flavonoid, isoflavone and proanthocyanidin (excluding monomers) content of selected foods served as the main source to derive values[16-18]. Total flavonoids were thus calculated as the sum of all available values from these three USDA databases. Additionally, values from biochemical analysis from mainly animal-based foods performed by Kuhnle *et al.* were used[19]. Anthocyanidin values for bananas were removed according to Drossard *et al.*[20]. The procedure to assign values was as follows[21]: (1) 'direct match' for foods with a one-to-one match was assigned directly; (2) foods without a direct match were matched with a similar food or the mean of several similar foods based on the botanical family or order and morphology (size, colour and texture) (e.g. broccoli for romanesco); (3) foods without a close match were matched to the mean or median of a corresponding food group (e.g. median of available values of tropical fruits for lychee); (4) if values were only available from a different processing form (raw *v.* cooked or tinned), published retention[22] and/or yield[23] factors accounting for flavonoid losses during heating or weight changes due to water loss/gain were applied. Total flavonoid intake was calculated as the sum of flavonols, flavones, flavanones, flavan-3-ols including proanthocyanidins, anthocyanidins and isoflavones. Finally, the flavonoid content of all recipes (that were collapsed into ingredients in the first step) was calculated by proportionally summing up the flavonoid content of all single nutrients. All foods and ingredients from recipes were categorised into one of nineteen food groups. Isoflavones were analysed separately since this subclass of flavonoids has distinct properties as compared with the other groups. Evidence regarding the health effect of isoflavones is mixed, since they are oestrogenic, they might interfere with puberty onset. Therefore, it was of interest to investigate intake of this subclass separately.

Statistical analysis

Absolute mean daily energy and flavonoid intakes were calculated from the three recorded days. To assess the richness of flavonoids and isoflavones in the diet, intakes were adjusted for energy density per 4184 kJ. The absolute total flavonoid intake was used to calculate the relative contribution of the defined food groups and single foods to total flavonoid and isoflavone intake by age group and sex separately. To analyse time and age trends in dietary flavonoid intake, polynomial mixed models were used including both fixed and random effects using PROC MIXED in SAS version 9.4[24]. This procedure considers both the dependence between repeated measures within a person and the nested nature of the data, in which we assumed that children from the same family had a similar diet. Another advantage is that children are not excluded from the analysis when data for a certain time point are missing.

Total flavonoid density and isoflavone density were the dependent variables. The principal fixed effects were age (continuously in years) and time (continuously in years). Quadratic and cubic terms of age (age^2, age^3) and time ($time^2$, $time^3$) and the interaction between the age and time variables were considered as additional explanatory variables if they improved the fit statistics (Akaike information criterion and Bayesian information criterion). Lower values of Akaike information criterion and Bayesian information criterion as compared with the previous model corresponded with a better model.

Table 1. Estimated intake and density of total flavonoids and isoflavones of the diet of children and adolescents from the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study (10 758 dietary recalls, 1312 children) between 1985 and 2016

Age (years) (recalls (*n*), participants (*n*))	Intake (mg/d)						Density (mg/4184 kJ)					
	P10	P25	Median	Mean	P75	P90	P10	P25	Median	Mean	P75	P90
Total flavonoids												
Boys												
All	104·31	145·37	207·89	232·43	290·35	392·73	67·20	91·06	122·79	133·93	162·61	211·33
3–6 (1847, 577)	90·01	119·71	166·35	184·99	227·99	298·85	74·06	97·11	130·36	142·76	170·82	224·04
7–9 (1204, 469)	109·32	154·40	211·78	227·22	280·02	365·51	69·58	94·15	125·10	134·53	162·25	207·62
10–12 (1008, 399)	112·03	160·33	224·58	241·54	305·96	402·10	64·46	87·51	117·47	127·90	158·66	202·60
13–15 (805, 322)	129·50	186·22	259·71	285·10	362·18	470·25	66·25	89·17	119·33	129·12	159·88	205·66
16–18 (617, 246)	131·93	186·23	263·49	300·95	380·15	506·32	54·14	77·66	110·94	122·46	148·70	206·22
Girls												
All	97·82	136·77	196·39	217·66	270·56	366·77	73·07	99·51	133·77	145·75	176·38	233·13
3–6 (1802, 570)	80·89	110·42	152·31	168·75	211·75	271·68	73·65	98·10	128·87	143·50	174·09	230·42
7–9 (1136, 438)	111·56	151·43	204·99	223·70	271·70	358·83	78·44	104·76	138·47	148·61	177·96	233·13
10–12 (972, 378)	117·83	164·70	222·02	239·36	296·41	373·51	72·15	98·08	132·20	141·26	169·63	218·44
13–15 (762, 296)	111·05	162·52	241·12	263·83	334·25	437·59	69·24	97·61	138·46	148·48	184·14	239·58
16–18 (605, 245)	110·10	161·10	234·29	258·95	333·11	426·77	66·73	96·36	135·54	150·89	185·13	249·84
Isoflavones												
Boys												
All	0·038	0·051	0·073	0·725	0·164	0·986	0·025	0·031	0·042	0·433	0·088	0·580
3–6 (1847, 577)	0·031	0·041	0·055	0·676	0·140	0·757	0·026	0·032	0·042	0·550	0·110	0·607
7–9 (1204, 469)	0·042	0·052	0·069	0·466	0·133	0·884	0·026	0·031	0·040	0·277	0·074	0·534
10–12 (1008, 399)	0·044	0·057	0·076	0·676	0·142	0·854	0·025	0·031	0·040	0·367	0·068	0·459
13–15 (805, 322)	0·052	0·067	0·094	0·841	0·212	1·374	0·025	0·031	0·043	0·377	0·090	0·615
16–18 (617, 246)	0·055	0·076	0·112	1·306	0·252	2·287	0·024	0·031	0·046	0·572	0·103	0·817
Girls												
All	0·034	0·045	0·065	0·473	0·158	0·807	0·026	0·032	0·043	0·328	0·105	0·549
3–6 (1802, 570)	0·029	0·037	0·050	0·446	0·126	0·740	0·026	0·033	0·042	0·388	0·103	0·634
7–9 (1136, 438)	0·037	0·048	0·064	0·367	0·147	0·652	0·027	0·032	0·041	0·253	0·098	0·438
10–12 (972, 378)	0·042	0·053	0·070	0·421	0·136	0·695	0·026	0·032	0·041	0·262	0·078	0·484
13–15 (762, 296)	0·041	0·055	0·082	0·688	0·230	1·085	0·026	0·032	0·045	0·390	0·132	0·646
16–18 (605, 245)	0·042	0·059	0·085	0·568	0·272	1·152	0·026	0·033	0·050	0·319	0·151	0·624

The fixed effects were included when they were statistically significant. Significant linear age or time trends indicate the constant increase or decrease of the dependent variable in every year. Quadratic and cubic age and time trends represent the magnitude of the trend changes over the study period. Interaction between age and time was introduced because we assumed that the effect of the principal fixed effects, for example age, changes, depending on the values of one or more other independent variables, for example, time, that is, the age trend changed over the study period. Random effects were considered to account for the lack of independence between the repeated measures of the same participant and to allow variation between individuals and families with respect to the initial level and linear, quadratic and cubic age trends of the dependent variable. The covariance structures of the random effects were also chosen based on the Akaike information criterion and Bayesian information criterion.

Since there was a statistically significant interaction by sex and age ($P < 0{\cdot}0001$), the data for boys and girls were analysed separately. A P-value $< 0{\cdot}05$ was considered statistically significant. Because the single effect estimate of polynomial models cannot be interpreted, we used betas that predict the age and time trends and plotted these. The plots show the predicted total flavonoid and isoflavone intake over the course of the study period for different age groups. The course of the lines illustrates the time trend, and the distance between the lines indicates the age trend.

Results

Intake

On average, 8·2 (median: 6 and range: 1–16) 3-d WFR were available per child. Across all age groups, energy density-adjusted total mean flavonoid intake was lower in boys compared with girls (134 (SD 64) mg/4184 kJ per d *v.* 146 (SD 70) mg/4184 kJ per d) and was slightly skewed towards lower intakes (Table 1). Total median flavonoid was 123 (interquartile range 72) and 134 (interquartile range 77) mg/4184 kJ per d for boys and girl, respectively.

Total flavonoid density was lower in older boys compared with younger boys (122 *v.* 143 mg/4184 kJ per d), whereas among girls diet was characterised by a higher flavonoid density in adolescence than in childhood (151 *v.* 144 mg/4184 kJ per d). Isoflavone density was highly skewed towards lower intakes; overall, the median intake was the same in boys and girls (0·04 mg/4184 kJ per d), and the mean intake was slightly higher in boys than in girls (0·43 *v.* 0·33 mg/4184 kJ per d). Mean isoflavone density intake was lowest for boys 7–9 years of age and highest in the youngest and oldest age groups; in girls, intake was highest in the youngest and 13–15 years old. Median isoflavone density was similar across all age groups for boys and girls, with the highest intake in the oldest age group (0·046 *v.* 0·050 mg/4184 kJ per d, for boys and girls, respectively).

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Foods and food groups

Overall, the top five food groups that contributed most to total flavonoid intake were fruits (45·9/50·2 %), cereals (12·8/12·1 %), confectionery (12·4/11·7 %), drinks (10·8/9·9 %) and potatoes (4·1/3·9 %) in boys and girls, respectively. The top ten foods that contributed to total flavonoids in boys were apple with peel (15·0 %), strawberries (5·9 %), chocolate spread (3·9 %), orange juice (3·5 %), pasta (3·5 %), apple juice (3·0 %), herbal-fruit teas (2·7 %), grapes (2·1 %), ice tea (1·6 %) and milk chocolate (1·4 %), and in girls, apple with peel (17·1 %), strawberries (6·1 %), chocolate spread (3·5 %), orange juice (3·4 %), pasta (3·4 %), herbal-fruit tea (3·0 %), grapes (2·8 %), apple juice (2·4 %), plums (1·9 %) and milk chocolate (1·5 %) (Table 2). The total contribution of the top ten foods to total flavonoid intake varied little across age groups and sex and ranged from 39·2 to 48·4 % and 42·7 to 48·0 % for boys and girls, respectively. Food groups that contributed to isoflavone intake in boys were vegetarian and vegan products (44·3 %), cereals (33·4 %), convenience foods (6·0 %), cakes and savoury snacks (3·7 %), and dairy products (2·6 %) and in girls were cereals (33·4 %), vegetarian and vegan products (28·7 %), convenience foods (5·1 %), cakes and savoury snacks (3·7 %), and dairy products (2·6 %). The top ten foods that mainly contributed to isoflavone intake included different types of soya drink and foods containing soya flour such as breads and ready to eat meals (data not shown).

Trends

Only in boys, age and time were statistically significantly associated with total flavonoid density in the diet (Fig. 1). A linear downward trend of total flavonoid density over the course of age was observed for boys, with an increase over time. In girls, total flavonoid density was associated neither with age nor with time. The observed data for total flavonoid density in girls however suggest a linear increase with increasing age and over the course of the 31-year study period.

The covariance structure that considers the correlation between similarities within families and the repeated measurements on the same subject for the models of total flavonoid density were an unstructured and a one banded Toeplitz for boys and an unstructured and a first-order auto-regressive for girls, respectively.

For boys, isoflavone density followed a U-shaped age trend with a decrease up to the age of 9 years and a slightly steeper increase up to the age of 18 years beyond the intake at the age of 3 years (Fig. 2). For girls, isoflavone density followed a U-shaped age trend with a decrease up to the age of 9 years and a more gradual increase up to the age of 15 years lower than the intake at age 3; this was followed by a slight decrease up to the age of 18 years. Neither among girls nor among boys isoflavone density changed over the course of the study period.

The covariance structure that considers the correlation between similarities within families and the repeated measurements on the same subject for the models of isoflavone density were a first-order factor analytic for girls for repeated measurements on the same child and an unstructured matrix for both random statements in boys.

Discussion

This study showed that boys had a slightly lower total mean flavonoid density compared with girls. However, median isoflavone density was the same in boys and girls. Furthermore, flavonoid intake in the diet stemmed from a range of different foods and food groups. Only in boys, age and time were statistically associated with flavonoid density in the diet. For both sexes, only age was statistically associated with isoflavone density.

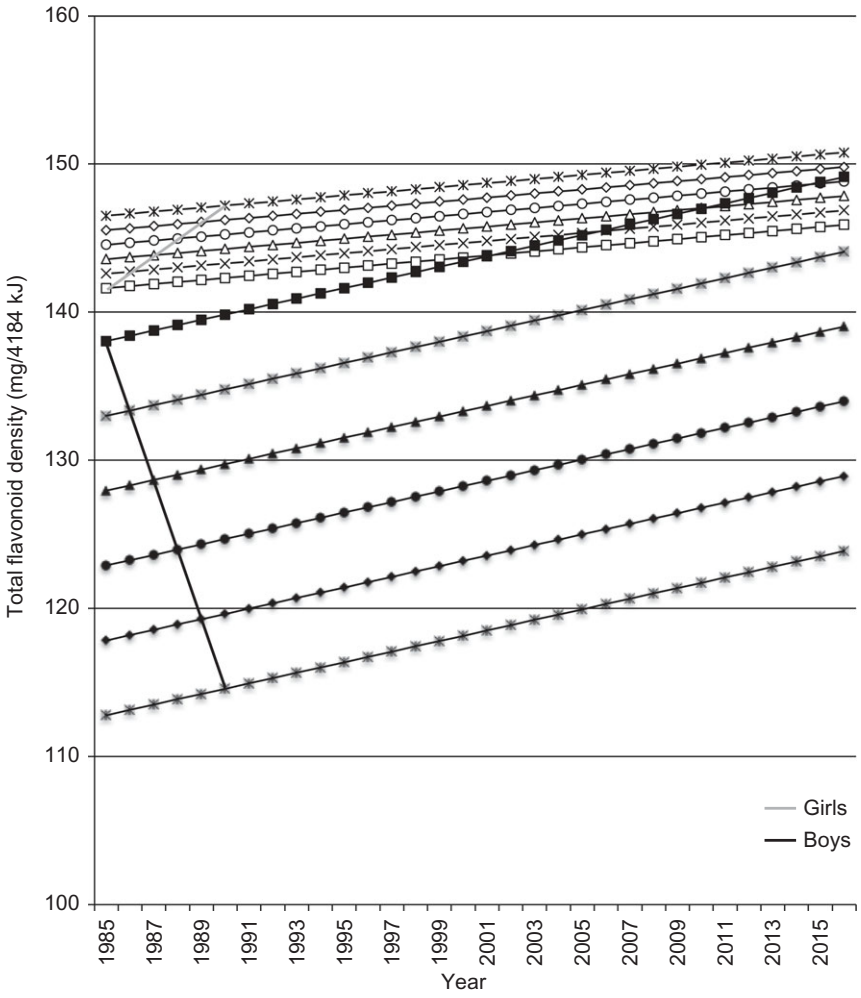
Compared with our results, mean total flavonoid intake in Australian children was 2- to 5-fold lower in 2–3- and 16–18-year-olds, respectively[7]. A likely explanation would be that proanthocyanidins were not estimated in this study. In the DONALD study, mean flavonoid intake excluding proanthocyanidins was similar (51 mg/4184 kJ per d). If this had been estimated in the Australian cohort, proanthocyanidin intake would have been considerably higher, for example, Vogiatzoglou *et al.*[25] estimated proanthocyanidin intake in 14–18-year-old Germans at 168·6 mg/d. Furthermore, differences might be explained by distinct dietary patterns, tea contributed to intake across all ages in Australian children, whereas in the present study black tea was only a main source in the oldest age group (Table 2). Other reasons are the use of a single 24-h dietary recall or the use of an older less complete version of the USDA database. In Chinese female adolescents, total flavonoid intake was also considerably lower (20 mg/d) and did not vary much between the assessment methods used (24-h dietary recall and FFQ); however, this was only estimated from two flavonoid subclasses and intake is therefore underestimated[9]. Apples contributed most to intake, which is in line with our findings.

In a cross-sectional study of Spanish children, the mean flavonoid intake assessed with 24-h recalls was much lower (70·7 mg/d) compared with our estimate, although this was also estimated from six flavonoid subclasses. Furthermore, intake was higher in older age groups; however, findings were not adjusted for energy[8]. To enhance comparability across age groups, especially in children, it is therefore desirable to also report intake by energy densities. The major dietary sources of flavonoids in the studies described above were apples, tea, potatoes, lettuce and oranges[7,9]. This was similar to the present study, in which contributing foods were either foods with a high flavonoid content (strawberry) or those consumed in large quantities (apple and pasta). Foods not listed in other studies that were contributors in the present study were ‘ice-tea’ and ‘chocolate spread’. This might be a result of assigning flavonoid values at the ingredient level, providing a higher level of detail. Black tea and cocoa were the main contributors to ice-tea and chocolate spread, respectively. But, this could also be explained by cultural differences in food choices. In the HELENA study, flavonoid intake was comparable with our study[10].

There are a number of scientific explanations for the observed difference in flavonoid intake between boys and girls. The decrease in flavonoid intake in boys with increasing age might be the result of becoming more independent and concurrently letting go of parental rules and healthy dietary behaviour[6,7]. Furthermore, another explanation might be that boys simply do not like the taste for fruits and vegetables

Table 2. Top ten foods contributing to total flavonoid intake by age group

Age group (years)...	3–6			7–9			10–12			13–15			16–18		
	Food	Participants	%	Food	Participants	%	Food	Participants	%	Food	Participants	%	Food	Participants	%
Boys															
Dietary records	1847	577		1204	469		1008	399		805	322		617	246	
1	Apple with peel		18·7	Apple with peel		17·6	Apple with peel		15·0	Apple with peel		11·6	Apple with peel		8·8
2	Strawberries		7·1	Strawberries		5·8	Strawberries		5·5	Strawberries		5·1	Strawberries		5·1
3	Apple juice		5·7	Chocolate spread		3·9	Chocolate spread		4·4	Chocolate spread		4·4	Orange juice		5·0
4	Herbal-fruit tea		3·1	Apple juice		3·4	Orange juice		3·6	Pasta		4·2	Pasta		5·0
5	Grapes		2·9	Pasta		3·4	Pasta		3·3	Orange juice		4·0	Chocolate spread		4·5
6	Orange juice		2·7	Orange juice		3·0	Herbal-fruit tea		3·1	Ice tea		2·8	Ice tea		3·7
7	Chocolate spread		2·7	Herbal-fruit tea		2·5	Apple juice		2·6	Herbal-fruit tea		2·6	Black tea		1·9
8	Pasta		2·5	Cocoa		2·4	Grapes		1·9	Apple juice		2·4	Herbal-fruit tea		1·8
9	Milk chocolate		1·5	Grapes		1·9	Ice tea		1·5	Grapes		1·8	Carbonated mineral water and apple juice 60 %		1·7
10	Pear		1·5	Plums		1·7	Milk chocolate		1·4	Milk chocolate		1·5	Apple juice		1·7
Total			48·4			45·5			42·3			40·4			39·2
Girls															
Dietary records	1802	570		1136	438		972	378		762	296		605	245	
1	Apple with peel		18·5	Apple with peel		18·5	Apple with peel		16·2	Apple with peel		15·2	Apple with peel		16·2
2	Strawberries		7·3	Strawberries		7·0	Strawberries		5·4	Strawberries		5·1	Strawberries		4·6
3	Apple juice		3·7	Chocolate spread		3·5	Chocolate spread		4·3	Orange juice		4·2	Pasta		4·1
4	Grapes		3·5	Orange juice		3·3	Orange juice		4·0	Chocolate spread		3·6	Orange juice		3·9
5	Herbal-fruit tea		3·2	Pasta		3·3	Pasta		3·5	Pasta		3·3	Herbal-fruit tea		3·6
6	Pasta		3·0	Apple juice		2·8	Herbal-fruit tea		3·2	Herbal-fruit tea		2·8	Chocolate spread		3·4
7	Chocolate spread		2·8	Herbal-fruit tea		2·5	Grapes		2·5	Ice tea		2·7	Black tea		2·9
8	Orange juice		2·2	Grapes		2·4	Apple juice		2·0	Grapes		2·6	Grapes		2·7
9	Plums		2·1	Plums		2·3	Plums		1·7	Instant mashed potato		1·7	Plums		2·3
10	Pear		1·8	Cocoa		2·2	Milk chocolate		1·6	Milk chocolate		1·5	Ice tea		1·9
Total			48·0			47·7			44·4			42·7			45·8



	Boys*		Girls†	
	β (SE) (mg/d)	*P*	β (SE) (mg/d)	*P*
Age (continuous 3–18 years)	−1·685 (0·26)	<0·0001	0·326 (0·30)	0·284
Time per study year (1985–2016)	0·358 (0·16)	0·0257	0·138 (0·18)	0·437

Age (continuously in years) and time (continuously in years) trends of flavonoid density were tested using polynomial mixed/effects regression models.
* Model for boys contains a random statement for the family level with an unstructured covariance structure and a random statement for the person level with a one banded Toeplitz covariance structure.
† Model for girls contains a random statement for the family level with an unstructured covariance structure and a random statement for the person level with a first-order auto-regressive covariance structure.

Fig. 1. Predicted polynomial mixed models of age and time trends in flavonoid density of 1312 (10 758 dietary records) Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study participants (3–18 years) between 1985 and 2016. (—□— and —■— 3 year olds; —×— and —✳— 6 year olds; —△— and —▲— 9 year olds; —○— and —●— 12 year olds; —◇— and —◆— 15 year olds; —x— and —✳— 18 year olds, for boys and girls, respectively). As an example, the black line follows the intake of a boy who was 3 years of age in 1985; the grey line follows the intake of a girl who was 3 years of age in 1985.

and/or prefer other foods that have a higher energy density[5]. Also, in girls, puberty is a period in which they form their own identity, and the increase in flavonoid intake with increasing age in girls might be a result of girls putting great emphasis on their appearance. As a result, they might adopt a healthy diet that is abundant in fruits and vegetables[6].

Chocolate was another important food source in children, although it was not in the top ten foods in all age categories.

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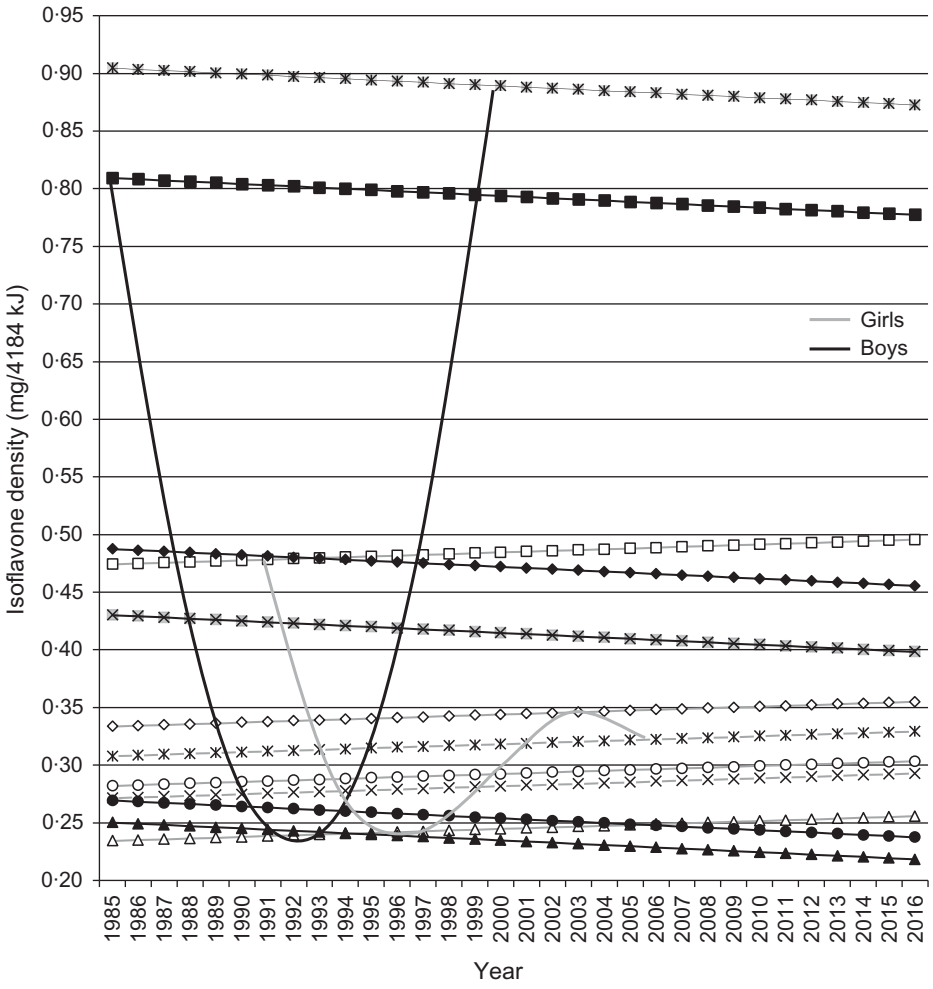

	Boys*		Girls†	
	β (SE) (mg/d)	*P*	*β* (SE) (mg/d)	*P*
Age (continuous 3–18 years)	–0·226 (0·086)	0·0086	–0·2 (0·07)	0·0049
Age^2	0·0011 (0·004)	0·0054	0·018 (0·007)	0·010
Age^3			–0·0005 (0·0002)	0·028
Time per study year (1985–2016)	–0·001 (0·005)	0·823	0·0007 (0·0027)	0·80

Age (continuously in years) and time (continuously in years) trends of flavonoid density were tested using polynomial mixed/effects regression models.
* Model for boys contains a random statement for the family level with an unstructured covariance structure and a random statement for the person level with an unstructured covariance structure.
† Model for girls contains a random statement for the person level with a first-order auto-regressive covariance structure.

Fig. 2. Predicted polynomial mixed models of age and time trends in isoflavone density of 1312 (10 758 dietary records) Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study participants (3–18 years) between 1985 and 2016. (—□— and —■— 3 year olds; —×— and —✱— 6 year olds; —△— and —▲— 9 year olds; —○— and —●— 12 year olds; —◇— and —◆— 15 year olds; —×— and —✱— 18 year old, for boys and girls, respectively). As an example, the black line follows the intake of a boy who was 3 years of age in 1985; the grey line follows the intake of a girl who was 3 years of age in 1991.

With increasing age, other foods became more important contributors, for example, tea is rich in flavonoids and contributed only in the highest age group. Contribution of the top ten foods to intake decreased with increasing age, which indicates a more diverse diet among older children compared with the younger ones. Seasonality was not considered in the analysis; however, the WFR were equally distributed across the year (data not shown).

Isoflavone intake was highly skewed towards lower intakes, which might be the result of the occasional consumption of isoflavone-rich foods such as soya drinks and tofu. In addition, especially processed foods such as ready to eat meals and meat products are a source of isoflavones. In the present study, many organic breads contained soya flour (data not shown).

To our knowledge, this is the first study to investigate age and time trends of total flavonoid and isoflavone density. The decreased flavonoid intake in boys over the course of age was also observed for anthocyanidin intake in the DONALD study, whereas this was not seen in girls[26]. Although an increased intake over the course of time and with increasing age can be described for girls, this was not statistically significant. This is in line with a previous analysis of the DONALD data of food groups in which the 15-year time trend for fruit and vegetables was not statistically significant either[27].

Public health perspective

From a public health perspective, the decreasing flavonoid intake over the course of age in boys deserves attention. However, in order to fully judge whether these trends are beneficial or detrimental, the food sources of flavonoid intake should be considered. Although fruits were the main contributor to total flavonoid intake, other food groups may be regarded as less healthy. For example, the food group confectionery was a large contributor to total flavonoid intake, mainly because it included chocolate, but is not recommended as part of a healthy diet. To elucidate the relevance of the observed age and time trends for a healthy diet, future analyses should additionally investigate trends in food group intakes.

Strengths and limitations

The main strengths of this study are the assessment of dietary intake by means of 3-d WFR and the large number of collected records. WFR enable the detailed recording and quantification of all foods and beverages consumed. Together with the longitudinal study design, these data are ideal for modelling trends over time and across age. The USDA database was used to assign values to the foods consumed in the DONALD study. This database is widely used which enhances comparability with other studies. Furthermore, the database covers a wide range of geographical regions and food varieties, which also apply to foods consumed in Germany. An inherent weakness of food composition tables is that the variability of flavonoids in foods as a result of climate, soil, processing and storage is not considered[28]. However, we partly accounted for food processing by applying yield and retention factors. Because of a higher level of detail of 3-d WFR as compared with an FFQ, more foods had to be assigned a value for total flavonoids. Taken together with the incompleteness of food composition databases, values for flavonoid subclasses were not assigned, as the larger number of unknown values would have introduced a level of uncertainty. Furthermore, weighing all consumed foods and beverages might have been burdensome to the participant and might have led to a change in intake due to an increased awareness or burden. Another limitation is that the DONALD participants are non-representative of the general German population as they have a higher socio-economic status[14]. However, dietary recommendations derived from the DONALD study were similar to the nationwide representative EsKiMo study[29,30].

Conclusion

Intake of flavonoids in our German study population is largely comparable to other studies. The overall observed downward secular trend of flavonoid intake in boys deserves some attention. Future initiatives might focus at maintaining a high flavonoid-dense diet as children age, specifically among boys.

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The authors declare there are no conflicts of interest.

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