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Daily Polyphenol Intake in France from Fruit and Vegetables[1]

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Abstract

The objective of this study was to create a French database on the polyphenol content of fruit and vegetables as uncooked fruits and vegetables and then to evaluate polyphenol intake through fruit and vegetable consumption in France. To achieve this, we used the Folin-Ciocalteu method adapted to fruit and vegetable polyphenol quantitation (1). Vegetables with the highest polyphenol concentration were artichokes, parsley, and brussels sprouts [>250 mg of gallic acid equivalent (GAE)/100 g fresh edible portion (FEP)]; fruits with the highest concentrations were strawberries, lychees, and grapes (>180 mg of GAE/100 g FEP). Conversely, melons (Cantaloupe *cv.*) and avocados had the lowest polyphenol concentration for fruits and vegetables, respectively. Based on fruit consumption data, apples and strawberries are the main sources of polyphenols in the French diet, whereas potatoes, lettuces, and onions are the most important vegetable sources. Total polyphenol intake from fruit is about 3 times higher than from vegetables, due to the lower polyphenol concentration in vegetables. The calculation of polyphenol intake, based on both assessment methods used [(Société d'Études de la Communication, Distribution et Publicité (SECODIP) and Supplémentation en Vitamines et Minéraux Antioxydants (SUVIMAX)], showed that apples and potatoes provide approximatively half of the total polyphenol intake from fruit and vegetables in the French diet. J. Nutr. 136: 2368–2373, 2006.

Introduction

Epidemiological studies indicate that fruit and vegetables have protective effects against degenerative diseases such as cancer and cardiovascular disease (2,3). The benefit ascribed to diets rich in fruits and vegetables could also be due to the avoidance of less desirable components in foods of animal origin, such as saturated fats, pyrolysis mutagens, oxidized cholesterol, etc., and also to the intake of diverse antioxidant compounds, such as vitamin C and the main dietary carotenoids and polyphenols. Because polyphenols represent a wide variety of diverse structures from different subclasses (flavonoids, phenolic acids, lignans, proanthocyanidins, etc.), it is difficult to estimate the total polyphenol content. A food database on flavonoids, a class of polyphenols, was recently published by the USDA (4), based on the quality evaluation system reported by Holden et al. (5). Such a database is extremely useful for epidemiological studies on the relation between dietary flavonoids and health. However, many of phenolic compounds escape HPLC/UV quantification, because there is a lack of commercially available standards and because of the presence of unidentified compounds leading to underestimation of total polyphenol content. Recently, Vinson et al. (6,7) reported data on the total polyphenol content of various fruits and vegetables. This content was colorimetrically measured by the Folin-Ciocalteu reaction after correction for ascorbic acid contribution. We recently proposed a similar colorimetric method for polyphenol quantification (1). The aim of this study was primarily to use this method to build a French database on the polyphenol content of fruit and vegetables. Subsequently, French daily polyphenol intake was estimated, using both information from a panel on fruit and vegetable purchases and 6 dietary records from a large French intervention study.

Materials and Methods

Sampling procedure. For each fruit and vegetable, a statistical sample plan was created to take into account the variety, the main geographical origin (France, Italy, Morocco, Spain, etc.), the harvest season, and the consumption levels. To be statistically representative, all the fruit and vegetables were sampled at national markets, which are the first step of the fruit and vegetable distribution chain to local markets. The edible

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part analyzed was determined according to usual French consumer habits. However, given the diversity of French behavior, we chose to keep the peel of apples, peaches, and eggplants. Citrus fruits were peeled roughly. Seeds were discarded for all the fruits. In stone fruit, the stone was removed and the peel kept. Most vegetables were home-prepared as raw material before freeze-drying stabilization.

Preparation and stabilization of homogeneous samples. A sample (30 fruits or vegetables) was taken randomly from a large selection (between 100 and 500). Preliminary studies were carried out to statistically validate the number of fruits and pieces in a sample, according to the Hardley test. This validation was done on apples, oranges, apricots, and strawberries, with 5 lots of 5, 15, or 30 fruits. No significant variation of total polyphenol content (TPC)[11] was observed with lots of 30 fruits.

Each fruit or vegetable was cut into 4 pieces and a part was discarded (peel, seeds, or stalks) as previously described. The 2 opposite sides (60 pieces) were taken, immediately frozen in liquid nitrogen, and freeze-dried. After freeze-drying, samples were blended in a Waring Blender and 10 g amounts of freeze-dried material were put in special protection bags to avoid any storage degradation (FA31, Parembal). All samples were stored at −20°C until analysis.

For fruits with a high sugar content (dates and figs), freeze-drying was not possible, thus samples were frozen directly in liquid nitrogen and stored at −20°C. Lastly, the lipid fraction of avocado was extracted with hexane before subjecting the defatted material to the usual procedure. This stabilization procedure did not affect TPC.

Determination of polyphenol content. Freeze-dried or frozen material (from 300 mg to 1 g) was homogenized with 10 mL of extraction solution (acetone:water, 7:3 vol:vol) for 10 min. The raw extract was obtained after filtration (Whatman). The complete analytical procedure was performed per Georgé et al. (1). Polyphenols are commonly determined using Folin-Ciocalteu reagent, which interacts with other different reducing nonphenolic substances and leads to an overestimation of polyphenol content. In our method, solid phase extraction (Oasis HLB) was carried out on the raw extract to eliminate the water-soluble reducing interferences, including vitamin C. Colorimetric correction was performed by subtracting interfering substances contained in the water washing extract to the raw extract.

Data from the Société d'Études de la Communication, Distribution et Publicité (SECODIP) panel were used to estimated fruit and vegetable consumption. SECODIP is a panel of ~2000 households that register once/wk, 13 times/y all fruits and vegetables purchased. This does not include fruit and vegetables eaten out of the household. We included fruit and vegetables that are produced at home [Internal source CTIFL (Annick Bellamy)]. Individual intake was estimated by dividing the purchases and/or production by the number of people in the household. Waste percentage was estimated to determine the TPC of the edible part.

For individual dietary assessment, we used data from the Supplémentation en Vitamines et Minéraux Antioxydants (SUVIMAX) study, a double-blind, placebo-controlled, primary prevention trial undertaken to determine whether supplementation with antioxidant vitamins and minerals at nutritional doses can reduce the incidence of cancers and cardiovascular diseases. The rationale, design, and methods of the study, as well as the major characteristics of the participants, have been described in detail elsewhere (8,9). Data on dietary intake were obtained through 24-h records that participants were asked to complete every 2 mo (altogether 6 times/y). Recording guidelines were provided in a manual containing photographs showing 3 portions sizes, along with the 2 intermediate and 2 extreme positions; a total of 7 choices were available to indicate the consumed portion. Photos of portion sizes were previously validated using 780 subjects in a pilot study (10). In total, 2795 men and 3844 women (aged 35–60 y) who completed at least 6 records in the first 2 y of the study were included in these analyses. The mean intake of the completed records was taken for each fruit and vegetable and expressed in g/d. The SUVIMAX study has been approved by the ethical committee for studies with human subjects (CCPPRB no. 706) of Paris-Cochin, and the Commision National Informatique et Liberté (CNIL no. 334641), which advocates that all medical information is confidential and anonymous.

To obtain the amount of polyphenols consumed, the amount of fruit or vegetable consumed in grams/d was multiplied by the polyphenol content in the fruit or vegetable. When an entry in the food consumption data was limited compared with the polyphenol content data, if possible, a weighed mean, based on proportions sold of each variety of fruit, was calculated. For example, the weighed mean content of the several apple varieties was taken and multiplied by daily apple intake to calculate the polyphenol consumption from apples (48% Golden delicious + 0.14% Gala + 0.11% Granny Smith + 0.09% American Red + 0.08% Braeburn + 0.05% Fuji + 0.05% Reinette).

Results and Discussion

In this study, we measured total polyphenol content and expressed it as GAE (slope = 0.012, R^2 = 0.99). As shown by George et al. (1), gallic acid response represents the mean response of all the major polyphenol compounds in fruit and vegetables as aglycones and conjugates (quercetin and quercitrin, catechin and procyanidin mixture, and caffeic and chlorogenic acid). Our results may therefore differ from those of Vinson et al. (6,7) or Hertog et al. (11), who expressed total polyphenol content in catechin and quercetin equivalent, respectively. Our previous study (1) on rapid TPC analysis was validated on fruit-derived products.

Total polyphenol content of fresh fruit. Strawberries (from Spain) had the highest polyphenol content [263.8 mg of GAE/100 g FEP (**Table 1**)]. Vinson et al. (5) placed strawberries in 10th position, with red grapes, bananas, and apples being reported to be the 3 richest fruits, respectively. They reported 133.4 mg of catechin equivalent/100 g FEP in this fruit; this estimate is possibly due to a difference in variety and origin. However, other authors have measured total polyphenol contents in 6 varieties of strawberries (12) and quoted a range from 317.2 to 443.4 mg of GAE/100 g FEP, depending on the cultivar. Vitamin C, which acts as a reducing compound in colorimetric assays, was not removed in this previous work and led to an overestimate of total polyphenol content.

Lychees (Kwaymay variety) had the second highest polyphenol content for fruit, with 222.3 mg of GAE/100 g FEP, and was thereby the richest tropical fruit.

Grapes, usually known for their high polyphenol contribution (white and black mean value: 195.5 mg of GAE/100 g FEP, included red, pink (both from Chile), and white varieties (Italy). Due to its high proanthocyanidin content (61 mg/100 g FEP), as recently reported by Gu et al. (13), the red grape (Alphonse Lavallée var.) had the highest polyphenol concentration, roughly twice that of the white (275.5 vs.134.1 mg of GAE/100 g FEP). Cantos et al. (14) reported lower values in red and white table grape varieties [11.49 and 36.12 mg in Dominga (white) and Flame Seedless (red) varieties, respectively]. Again, the determination procedure could partially explain this substantial difference; the total polyphenol content was expressed in this previous work as the sum of anthocyanins, flavonols, hydroxycinnamic derivatives, and flavanols determined by HPLC, and many may have escaped HPLC quantification because of a lack of available commercial standards.

The relatively low value obtained for the most consumed banana variety (Cavendish var.), 51.5 mg of GAE/100 g FEP, did not tally with the literature data. In fact, Vinson et al. (7)

[11] Abbreviations used: FEP: fresh edible portion; GAE: gallic acid equivalent; SECODIP: Société d'Études de la COmmunication, DIstribution et Publicité; SUVIMAX: SUpplémentation en VItamines et Minéraux AntioXydants; TPC: total polyphenol content.

TABLE 1 TPC of fresh fruit

Rank	Common name	Fruit lot	Mean TPC[1]	Min[2]	Max[3]
			mg of GAE/100 g FEP		
1	Strawberry	1	263.8	–	–
2	Lychee	1	222.3	–	–
3	Grape	3	195.5	134.1	275.5
4	Apricot	4	179.8	103.1	318.3
5	Apple	9	179.1	90.2	300.0
6	Date	1	99.3	–	–
7	Cherry	1	94.3	–	–
8	Fig	1	92.5	–	–
9	Pear	4	69.2	40.7	148
10	White nectarine	1	72.7	–	–
11	Passion fruit	1	71.8	–	–
12	Mango	1	68.1	–	–
13	Yellow peach	1	59.3	–	–
14	Banana	1	51.5	–	–
15	Pineapple	2	47.2	32.7	61.6
16	Lemon	2	45.0	34.6	55.3
17	Yellow nectarine	1	44.2	–	–
18	Grapefruit	2	43.5	39.3	47.7
19	Orange	5	31.0	27.0	36.5
20	Clementine	3	30.6	22.7	38.7
21	Lime	1	30.6	–	–
22	Kiwi	2	28.1	26.1	30.0
23	Watermelon	1	11.6	–	–
24	Melon	1	7.8	–	–

1 Values are means, $n = 3$; RSD <5% for each lot analyzed.
2 Minimum concentration when $n \geq 2$.
3 Maximum concentration when $n \geq 2$.

reported 325 mg of catechin equivalent/100 g FEP in bananas. This large difference could be also attributed to the variety or origin or to vitamin C interference (8.7 mg of ascorbic acid/100 g FEP), as reported in the USDA database (15). Furthermore, Pilar Cano et al. (16) reported a notable quantity of dopamine (17.37 mg/100 g FEP) in the Enana cultivar cultivated in the Canary Islands (Spain). With regard to dopamine structure, this compound may also interact with the Folin-Ciocalteu reagent and may have been partially eliminated, along with other interferences, in our method. Lastly, mangos (no. 20, Keitt cultivar assayed) had a content of 68.1 mg of GAE/100 g FEP. Soong and Barlow (17) reported 240 mg of GAE/100 g FEP in an unknown cultivar purchased in Singapore. Vitamin C response correction (27.7 mg of ascorbic acid/100 g FEP) may partially explain such a difference.

Apricots (no. 4) had the highest mean polyphenol concentration of the fruits (179.8 mg of GAE/100 g FEP on mean), followed by white nectarines (no. 10) and yellow peaches (no. 13). The variety effect must again be stressed, in that the Hart Grant variety was >3 times as rich as Goldrich (318.3 and 103.1 mg of GAE/100 g FEP, respectively).

Seven apple varieties (Braeburn, Fuji, Gala, Golden delicious, Granny Smith, Reinette, and American Red type) were analyzed in this study. Except for the Fuji variety, with 90.2 mg of GAE/100 g FEP, and Reinette, with 300 mg of GAE/100 g FEP, the other varieties were close to the mean value of 139 mg of GAE/100 g FEP. These data highlighted the effect of variety on TPC content and agreed with the previous work of Vrhovsek et al. (18), who reported a data range of 66.2 to 211.9 mg of catechin/100 g FEP for the Fuji and Renetta varieties, respectively, and a mean value of 110 mg of catechin/100 g FEP.

Among citrus fruits, the mean total polyphenol value ranged from 30 to 45 mg of GAE/100 g FEP. In a previous work on fresh citrus juice from Israel, Gorinstein et al. (19) quoted higher values in orange and grapefruit juices (*var.* Shamouti and Red Star Ruby, and Sunrise, respectively), with 96.2 and 90.7 mg of GAE/100 g FEP, respectively.

Total polyphenol content of fresh vegetables. Artichoke (no. 1) (*Cynara scolymus* L.), (Violet de Provence and Camus var.) had the highest polyphenol content, with a mean value of 321.3 mg of GAE/100 g FEP (**Table 2**). The data range (202.4–438.1) tallied with the results published recently by Dogan et al. (20) that quoted 425 mg of catechol equivalent/100 g FEP.

Brussels sprouts (no. 3; 257.1 mg of GAE/100 g FEP) is a cool season crop that belongs to the species *Brassica oleracea*, which includes cauliflower, broccoli, kale, and collard. The total polyphenol contents among these edible flowers are worth emphasizing, as brussels sprouts (no. 3) contain 20.5 times more than cauliflower (no. 25) and 2.6 times more than broccoli (no. 5). Our data for broccoli (98.9 mg of GAE/100 g FEP) were higher than the previous figures reported by Ninfali and Bacchiocca (21) and Zhang and Hamauzu (22), who reported 69.27 mg of caffeic acid/100 g FEP in the Cymosa variety from Italy and 34.5 mg of GAE/100 g FEP in the florets of broccoli from Nagano (Japan).

TABLE 2 TPC of fresh vegetables

Rank	Common name	Fruit lot	Mean TPC[1]	Min[2]	Max[3]
			mg of GAE/100 g FEP		
1	Artichoke heart	3	321.3	202.4	438.1
2	Parsley	1	280.2	–	–
3	Brussels sprout	1	257.1	–	–
4	Shallot	1	104.1	–	–
5	Broccoli	2	98.9	89.3	108.4
6	Celery	1	84.7	–	–
7	Onion	1	76.1	–	–
8	Asparagus	2	14.5	8.0	72.2
9	Eggplant	2	65.6	53.6	77.6
10	Garlic	1	59.4	–	–
11	Turnip	1	54.7	–	–
12	Salad[4]	7	35.6	18.7	145.0
13	Celeriac	1	39.8	–	–
14	Radish	1	38.4	–	–
15	Pea	1	36.7	–	–
16	Leek	1	32.7	–	–
17	Red bell pepper	1	26.8	–	–
18	Cherry tomato	2	26.4	25.6	27.2
19	Potato	1	23.1	–	–
20	Zucchini	2	18.8	10.9	26.7
21	Green bell pepper	1	18.2	–	–
22	Chicory	1	14.7	–	–
23	Tomato	5	13.7	9.8	26.0
24	Fennel	1	13.0	–	–
25	Cauliflower	1	12.5	–	–
26	Carrot	1	10.1	–	–
27	French string bean	1	10.0	–	–
29	Avocado	2	3.6	1.1	6.1

1 Values are means, $n = 3$; RSD <5% for each lot analyzed.
2 Minimum concentration when $n \geq 2$.
3 Maximum concentration when $n \geq 2$.
4 Mix of frisée, scarole, batavia, iceberg, feuille de chêne green and red, Lollo rossa red, and laitue beurre varieties.

Of the onion family (*Allium*) (shallot, no. 4; onion, no. 7 and garlic, no. 10), shallot, with 104.1 mg of GAE/100 g FEP, had the highest value, about twice as rich as garlic. Onion is one of the richest sources of quercetin (flavonol) in the human diet (23), with a mean value of 34.7 mg/100 g FEP (24), with quercetin representing >45% of the total polyphenol content. We found 76.1 mg of GAE/100 g FEP for onion, whereas Ninfali and Bacchiocca (21) and Vinson et al. (6) reported 24.4 mg of caffeic acid/100 g FEP in the Bianca della Regina cultivar (Italy) and 92.0 mg of catechin equivalent/100 g FEP, respectively. Such differences may be partially due to result expression (respective molecular weights of the reference compounds), the Folin-Ciocalteu response, or vitamin C interference.

Polyphenol intake estimated from fruit and vegetables purchased and produced per household. In purchased and home-produced fruit and vegetable quantities (SECODIP assessment method), apples represent ~30% of total consumed fruit (52.8 g FEP/d) (**Table 3**). This is not the case in the United States, where apples account for just 22% of total polyphenol intake (6). Conversely, strawberries and grapes rank 8th and 9th, respectively, in terms of consumption, while they are the 2nd and 3rd sources of polyphenol, with 18.2 and 17.6 mg of GAE/100 g FEP (albeit both roughly 10% of apple polyphenol concentration). Among citrus fruits, the relation between consumption rank and polyphenol intake for oranges is inverted, as they are the 2nd fruit in terms of consumption, but only the 8th source of polyphenol in the French diet. It is important to stress that 3/4 of oranges are consumed in processed form (juice, juice-based drinks, etc.), which explains the relatively low polyphenol intake from fresh fruit.

Among vegetables (**Table 4**), potatoes account for ~45% of total polyphenol intake, due to a high consumption level (203.4 g FEP/d). However, it must be quoted that substantial losses could occur during cooking (25). Indeed, 59% of all vegetables consumed are potatoes (on SECODIP weight basis), the second being tomato at only 10%. The artichoke is interesting in that despite its high polyphenol content (5th), it is not an important source, as consumption decreased from 1.4 to 1.1 g FEP/d over the period 2001–2004 (data not shown). In a similar manner, consumption of vegetables from the family *Brassica* (brussels sprouts, broccoli, and cauliflower) is low; despite to their high polyphenol content, brussels sprouts are only the 11th source of polyphenol intake (1.6 mg of GAE/100 g FEP).

A comparison of fruit/vegetable polyphenol intake sources with consumption (Tables 3,4) highlights the major role of fruit,

TABLE 3 French daily polyphenol intake (PI) (Fruits) based on SECODIP and SUVIMAX assessment methods

Common name	Total per capita			Polyphenol intake			Polyphenol intake RANK		
		SUV[1]			SUV			SUV	
	SEC[2]	Men	Women	SEC	Men	Women	SEC	Men	Women
	FEP g/d			mg GAE/d					
Apple	52.8	65.42	49.0	94.5	117.2	87.8	1	1	1
Apricot	4.3	3.83	4.02	7.7	6.9	7.2	7	5	5
Banana	16.9	11.97	7.42	8.7	6.2	5.1	5	6	7
Cherry	2.0	5.33	5.03	1.8	5.0	5.0	11	7	8
Clementine	13.0	5.06	6.28	4.0	1.5	2.7	9	12	13
Fig	–[3]	0.73	1.04	–	0.7	1.0	–	16	16
Grape	9.0	12.35	8.79	17.6	24.1	17.2	3	3	3
Grapefruit	5.0	4.96	7.21	2.2	2.2	3.2	10	11	12
Kiwi	4.4	4.83	6.61	1.2	1.4	2.0	13	13	14
Lemon	2.9	1.34	1.56	1.3	0.6	0.8	12	17	17
Lime	0.1	–	–	0.0	–	–	19	–	–
Lychee	0.3	0.09	0.06	0.7	0.2	0.1	16	19	20
Mango	0.4	0.43	0.65	0.3	0.3	0.5	17	18	18
Melon	9.5	11.84	11.47	0.7	0.9	3.5	15	14	11
Nectarine[4]	15.9	6.29	5.74	9.4	4.6	4.0	4	8	10
Orange	21.2	11.23	10.28	6.6	3.5	4.5	8	10	9
Passion fruit	–	0.01	0.03	–	0.0	0.0	–	21	21
Peach	–	7.3	7.46	–	4.3	5.4	–	9	6
Pear	12.3	14.15	11.33	8.5	9.8	10.5	6	4	4
Pineapple	1.9	1.75	2.16	0.9	0.8	1.3	14	15	15
Strawberry	6.9	10.94	11.73	18.2	28.9	30.9	2	2	2
Watermelon	1.6	0.95	0.61	0.2	0.1	0.2	18	20	19
Total	180.4	180.8	158.5	184.6	219.1	192.9			

[1] SUV, data based on SUVIMAX assessment method.
[2] SEC, data based on SECODIP assessment method.
[3] Not mentioned in the survey.
[4] Mix of white and yellow fruits.

TABLE 4 French daily polyphenol intake (Vegetables) based on SECODIP and SUVIMAX assessment methods

Common name	Total per capita			Polyphenol intake			Polyphenol Intake RANK		
		SUV[1]			SUV			SUV	
	SEC[2]	Men	Women	SEC	Men	Women	SEC	Men	Women
	FEP g/d			mg GAE/d					
Artichoke heart	1.1	2.39	2.46	3.5	7.7	7.9	5	4	2
Asparagus	1.3	2.87	2.58	0.2	0.4	0.4	23	22	21
Eggplant	2.2	2.65	2.9	1.4	1.7	1.9	13	13	13
Avocado	2.8	3.41	2.69	0.1	0.1	0.1	25	25	25
Bell pepper	2.7	2.41	2.36	0.6	0.5	0.5	19	20	20
Broccoli	1.2	4.48	4.92	1.1	4.4	4.9	15	5	5
Brussels sprout	0.6	1.09	0.83	1.6	2.8	2.1	11	7	10
Carrot	23.1	25.81	23.94	2.3	2.6	2.4	6	9	7
Cauliflower	4.0	6.51	6.93	0.5	0.8	0.9	20	18	17
Celeriac	0.9	1.69	1.43	0.4	1.4	1.2	21	15	16
Celery	0.9	6.67	5.75	0.8	2.7	2.3	17	8	8
Chicory	11.8	–[3]	–	1.7	–	–	8	–	–
Zucchini	10.8	8.64	9.14	2.0	1.6	1.7	7	14	14
Fennel	1.0	1.12	1.39	0.1	0.1	0.2	24	24	23
French string bean	2.9	22.61	21.03	0.3	2.4	2.2	22	11	9
Garlic	1.3	0.29	0.23	0.8	0.2	0.1	18	23	24
Leek	4.9	5.95	5.9	1.6	1.9	1.9	10	12	12
Onion	8.8	10.16	8.45	6.7	7.7	6.4	3	3	4
Parsley	0.6	0.28	0.22	1.6	0.8	0.6	12	19	19
Pea	0.1	6.99	5.45	0.1	2.6	2.0	26	10	11
Potato	203.4	90.04	63.48	47.0	20.8	14.7	1	1	1
Radish	3.5	2.79	1.99	1.3	1.1	0.8	14	17	18
Salad[4]	15.8	24.32	21.25	8.0	8.7	7.6	2	2	3
Shallot	1.7	0.46	0.32	1.7	0.5	0.3	9	21	22
Tomato	36.1	21.03	20.16	4.9	2.9	2.8	4	6	6
Turnip	1.7	2.35	2.3	0.9	1.3	1.3	16	16	15
Total	345.1	257.0	218.1	103.9	77.8	67.1			

[1] SUV, data based on SUVIMAX assessment method.
[2] SEC: Data based on SECODIP assessment method.
[3] Not mentioned in the survey.
[4] Mix of Frisée, scarole, batavia, iceberg, feuille de chêne green and red, Lollo rossa red, endive, and laitue beurre varieties.

which contributes >64% of total polyphenol intake. The prevalence of apples and potatoes in the French diet is also important, accounting for ~50% of total polyphenol intake from fruit and vegetables. This typical behavior is not seen in the U.S., where bananas and tomatoes are the main polyphenol sources among fruit and vegetables (17 and 8.7% of total intake, respectively), whereas potato is only 4th (5,6).

Polyphenol intake from fruits and vegetables estimated from 24-h dietary records. This second analysis uses quantities of fruit and vegetable actually consumed in France (SUVIMAX assessment method) and not only the bought and home-produced quantities (which can be misleading in terms of waste and processed products). Using the 2 approaches to calculate intake, the main polyphenol sources from fruit consumption were roughly the same, with apples, strawberries, and grapes being most important. Furthermore, the intake was similar for each gender, except for peaches, which were consumed slightly more by women. The 3 most consumed fruits accounted for ~70 and 80% of total fruit polyphenol intake for women and men, respectively, again highlighting the preponderance of apples, strawberries, and grapes in the French diet.

Of vegetables, potatoes, lettuces (iceberg, romaine, lolla rossa, and endive *cvs.*), onions, and artichokes were the main polyphenol sources for men. Despite the high polyphenol content of artichokes (321.3 mg of GAE/100 g FEP), it is not an important source, as consumption is low (2.46 and 2.39 g FEP/d for women and men, respectively). By contrast, potatoes have a lower polyphenol content (23.1 mg of GAE/100 g FEP), but a high mean consumption (63.48 and 90.04 g FEP/d for women and men, respectively) and are therefore the most important vegetable source. The 3 most consumed vegetables account for almost 45% of total vegetable polyphenol intake. In all, 74% of total polyphenol intake can be attributed to fruit consumption, with apples providing 30 and 40% for women and men, respectively. Overall vegetable consumption provides 77.8 mg of GAE/100 g FEP for men and 67.1 of GAE/100 g FEP for women.

If we consider the total polyphenol intake to be 1 g/d, as reported by Kühnau (26) or Scalbert and Williamson (27), our study suggests that fruit and vegetable intake accounts for 28% of daily polyphenol intake. Coffee, tea, wine, fruit juices, and cereals are the other main contributors. Nevertheless, further investigations are necessary to estimate polyphenol losses during processing and home culinary practices.

Furthermore, although total polyphenol content is an interesting parameter to include in epidemiological studies, it is still necessary to evaluate the different classes or structures to determine their biological activity, which greatly depends on their bioavailability (28,29). In fact, the available data suggest substantial variation in the absorption of the different classes of polyphenols and also variations within classes. For example, both anthocyanins and procyanidins appear to be poorly absorbed (<4%). By contrast, isoflavones and flavonols are better absorbed (from 9 to 52%). Nevertheless, polyphenols may act as antioxidants and have protective effects along the digestive tract (from mouth to colon), as suggested recently by Halliwell et al. (30).

In conclusion, of all fruits and vegetables studied, strawberries, lychees, grapes, artichokes, parsley, and brussels sprouts have the highest polyphenol contents (>190 mg of GAE/100 g FEP). Correlating the database on polyphenol content with the 2 dietary databases (i.e., obtained from fruits and vegetables purchased and produced per household and individual dietary records), we showed that apples and potatoes were the main fruit and vegetable, respectively, providing polyphenol intake. Both provide ~47% of total polyphenol intake from fruit and vegetables in the French diet.

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