Pol. J. Food Nutr. Sci., 2018, Vol. 68, No. 1, pp. 57–62
DOI: 10.1515/pjfns-2017-0007
http://journal.pan.olsztyn.pl

Original research article
Section: Food Quality and Functionality

Intake and Profile of Plant Polyphenols in the Diet of the Czech Population

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Key words: plant polyphenols, dietary intake, Phenol-Explorer database, Czech population

Nowadays, a great attention is paid to the biological activity of plant polyphenols and their potential importance for the human health. Therefore knowledge regarding the dietary intake of polyphenols and their particular subclasses has gained interest. In this report, the results of a pilot study evaluating the average polyphenol content in the Czech diet have been presented.

Knowledge of the average intake of plant polyphenols is an important contribution to the evaluation of the dietary pattern from the aspect of its health impact.

An annual average consumption of the main foods of plant origin (a total of 80 commodities) was estimated, using data from the Czech annual statistical report, in the entire Czech population in 2013. These values (kg/y) were multiplied with the contents of plant polyphenols in the same items as presented in the in the database Phenol Explorer.

The average intake of plant polyphenols was 426 mg/d. The prevailing polyphenols were chlorogenic acid, 82 mg/d (most important sources were potatoes, coffee, plums), followed by apigeninflavone, 79 mg/d (wheat), heneicosylresorcinol, 38 mg/d (wheat), ferrulic acid, 17 mg/d (wheat) and anthocyanin malvidin, 13 mg/d (red wine). These values are below the intake of polyphenols in the most EU countries.

These differences reflect – *inter alia* – the fact that beer having low content of polyphenols is a dominant commodity in Czech dietary pattern while fruit and vegetables as well as teas and coffee consumption is relatively low.

INTRODUCTION

Plant polyphenols belong to the broad group of non-nutritional, biological active natural compounds ubiquitously occurring in foods of plant origin. Their chemical structure is characterized by one or more hydroxylated benzene cycles and they are usually linked by a glycosidic bond to a sugar unit. Polyphenols are believed to be secondary physiological products of the plants. The basic, and the most numerous group of polyphenols are flavonoids (including anthocyanidins). They are followed by phenolic acids, stilbenes, and other phenolics, last but not least, are polyphenol dimers and polymerization products (*e.g.* tannins).

Extended experience with the relationship between dietary pattern and food composition on the one side and the health status of the population on the other side convincingly indicate that the plant components of the diet, including fruits, vegetables, legumes, cereals, teas, coffee, cocoa, and nuts, are associated with health support and promotion [Tresserra-Rimbau *et al*., 2013]. Plant polyphenols may influence many physiological functions. The regular intake of these substances is associated with a lower risk of cardiovascular mortality [Wang *et al*., 2014], protection against development of cancer [Ruiz & Hernandez, 2014] and type 2 diabetes [Carter *et al*., 2010], and age-related decrease of cognitive functions [Tresserra-Rimbau *et al*., 2014]. However, more detailed data showing the specific roles of single subclasses of polyphenols in health promotion and prevention of diseases are rather scarce.

Currently, the interest in plant polyphenols is focused on their occurrence in foods of plant origin, chemical structure, antioxidant activity, metabolism in human organisms (including bioaccessibility and bioactivity), and structural changes caused by technological processing of foods.

Comprehensive databases of polyphenol content in foods have been recently compiled and published, *inter alia* Phenol-Explorer [Neveu *et al*., 2010]. In effort to identify and recognize the biological effects of polyphenols, numerous animal experiments, studies on cell and tissue cultures, clinical research, and epidemiological studies were conducted in the last decade [Quinones *et al*., 2013; Zanotti *et al*., 2015; Sies, 2010]. In order to establish the actual benefit of plant polyphenols in disease prevention and in health support, the amount of substances which are considered to be effective should be evaluated as precisely as possible. Therefore, the polyphenol spectrum mapping in the diet which is regularly consumed by a population may be a useful tool for the evaluation of a real significance of diet in the public health defense and promotion. This will help to determine an opti-

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mal polyphenol intake and the desirable choice of those food sources that may contribute to the prevention of common, non-infectious diseases.

The aim of this pilot study was to estimate the average total intake of polyphenols in the diet of the Czech population and to take into account the intake of individual subgroups of these natural compounds as well as to identify the most frequent individual polyphenol representatives in the Czech diet. The objective was also to designate the foods which are the most significant sources of biologically-active polyphenols in Czech dietary pattern. According our knowledge, no in-depth relevant study aimed at polyphenol intake has been realized in the Czech Republic so far.

MATERIALS AND METHODS

Information resources and their processing

Outputs of statistical evaluation concerning average *per capita* and annual consumption of foods in the Czech Republic in 2013, taken from the presentation by the Czech Statistical Office, were applied; these data incorporate the total consumption of foods in the entire population and are equal to the sum = production + imports – exports – wastage – non--food use. These data were multiplied with the values of polyphenol content in foods as specified in the Phenol-Explorer database, version 3. These values were related to the glycosylated and/or esterified forms of polyphenols.

Average contents of polyphenols in a total of 80 items of food products of plant origin were estimated. These items constituted numerous food categories, namely: fruits, vegetables, potatoes, pulses, cereals, cocoa, coffee, teas, and alcoholic beverages. Because the consumption data about black and green tea, and white and red wine were not included individually in the database, we used the 50% : 50 % ratio of both types of tea and wine. This type of distribution of the total amount to the partial items is believed to not substantially affect evaluation of polyphenol intake in the population [Joudalová & Réblová, 2012].

Expressing average intake of various polyphenols

The contents of more than 400 chemical individuals having structural features of polyphenols excerpted from Phenol--Explorer and expressed in content values (mg/100 g), were multiplied with consumed quantities of their food sources in the Czech population and the average daily intake of polyphenols was assessed in mg/d. The evaluated polyphenols contained in the Czech diet were divided into basic classes, and subclasses derived from them:

– Flavonoids (flavones, flavonols, flavans, flavanols, catechins, isoflavans, chalcons, anthocyanins)
– Lignans
– Stilbenes
– Phenolic acids (hydroxybenzoic and hydroxycinnamic acids)
– Other phenolics (resorcinols and others).

The total average intake of fruits, vegetables, potatoes, cereals, pulses, cereals, beverages and other foods of plant origin (kg, L / capita and year) was counted. The average total intake

TABLE 1. Average annual consumption of the common foods of plant origin in the Czech population.

Food group	(kg/y) or (L/y)
Fruits	77
Vegetables	82.9
Cereals	143.4 (as raw grains)
Potatoes	68
Legumes	2.6
Coffee and tea	1.9 resp. 0.2
Beer and wine	147 resp. 18.8.
Spirits	6.5

TABLE 2. Groups of polyphenol order by size of their intake.

Groups of polyphenols	% of the total polyphenol intake
Hydroxycinnamic acids	30.4
Flavones	18.8
Flavanols	12.0
Other polyphenols	11.7
Anthocyanins	10.7
Flavonols	5.5
Lignans	4.4
Hydroxybenzoic acids	3.0
Flavanones	2.0
Dihydrochalcones	0.8
Dihydroflavonols	0.4
Stilbenes	0.3

of polyphenols and their subgroups and the order of polyphenol groups by size of their contribution in the Czech diet as well as the quantitatively most significant polyphenols were set out and tabulated.

RESULTS

The total intake of fruits and vegetables in the Czech population was 437.5 g/d. This value is somewhat above the European mean value which was stated in 2012 using FAO FBS estimates (429 g/d), and above the results for the Czech Republic (and in other European countries) which are included in the same report of Tennant *et al*. [2014]. It is desirable to note that the World Health Organization has recommended 600 g/d fruit and vegetables as an average consumption, *i.e*. the dose optimal for dietary non-communicable diseases intervention. Despite favorable values resulting from our calculations, various biases decreasing the real intake, *e.g.* destructive effects of home food processing on polyphenol structures, wastage after peeling and another treatment of vegetables *etc*.

TABLE 3. The quantitatively most frequent polyphenols in the Czech dietary pattern and their main sources.

Polyphenol subgroup	Polyphenol group	Source	Daily average intake (mg/d)
Apigenin	Flavone	Wheat	79.2
Coffeequinic acid	Chlorogenic acid	Potatoes, plums, coffee	81.5
Heneicosylresorcinol	Alkyl phenols	Wheat, plant oils	55.6
Ferrulic acid	Phenolic acid	Wheat, beer	20.7
Malvidin	Anthocyanin	Red wine, grapes	15.5
5-Caffeeolylquinic acid	Hydroxycinnamic acid	Coffee, apples	22.1
4-Hydroxy-benzoic acid	Phenolic acid	Beer	16.3
Pinoresinol+lariciresinol	Lignans	Cabbage	13.8
Cyanidin glucoside	Anthocyanin	Citruses	6.5

should be admitted. It is also worth mentioning that the statistical average food consumption being applied in our calculation covers the whole population and does not correct the large inter-individual differences. Similarly, some groups of foods providing numerous and very aggregated items (*e.g.* cereals *vs* rye, wheat bread, pasta, pastries and noodles) are calculated on the whole rather than individually. Nevertheless, interrelationships between the contents / intakes of each polyphenol species in our assessments can be considered as veracious.

In the Czech dietary pattern, there is – besides fruits and vegetables – yet another considerable intake of foods of plant origin enriching the diet with many phytonutrients including plant polyphenols such as lignans, flavan-3-ols and phenolic acids, tannins and isoflavonoids, as is presented in Table 1. Especially, beer consumption (*i.e.* 147 L/year *per capita*, one of the largest in the Europe) means the not inconsiderable contribution to the polyphenol spectrum in the Czech diet.

Polyphenols in foods are characterized by a great species and structural diversity which determines the nature of their biological activity in human organisms. The shares of individual polyphenol subclasses corresponding to our calculations were indicated in Table 2.

As to the interpretation of potential biological effects of phenolics, the absolute amount of individual substances has to be taken into account. The order of the individual polyphenol species by the size of their intake in the Czech population is given in Table 3.

DISCUSSION

This report is intended as a pilot study and contribution to the contemporary Europe-wide trend to critically reassess both the total and individual intake of plant polyphenols in human society. These are considered important phytonutrients and are supplied through the foods of plant origin. The polyphenols constitute a very numerous and heterogeneous group of compounds with over 500 various molecules and they provide various biological activities. Apart from the amount of polyphenols consumed in diet, their major dietary sources should regularly be considered and quantified.

The Czech population suffers from a great incidence of non-communicable civilization diseases and a low consummation of "healthy food", including the fruits and vegetables, has been assumed as a significant risk factor. According to our knowledge, detailed information about the size of dietary intake of polyphenols in the Czech population is still lacking.

The results of our investigation show that cereals (wheat flour) and potatoes, followed by red wine and by some kinds of vegetables (cabbage, peas) and fruit (citruses, apples, strawberries, plums), as well as cocoa, were prevailing contributors to the polyphenol intake in the Czechs. More specifically, hydroxycinnamic acids, flavones and other flavonoids (anthocyanins, flavanols, flavonols) and 5-heneicosyl-resorcinol were the most widely consumed representatives of polyphenols.

The total average polyphenol consumption 426.6 mg/d has been rather low and is greatly different from the intake in other European, as well as non-European, countries (Spain, France, Ireland, Brazil *etc*.). For comparison, analogous estimates from the other countries are given in Table 4.

This reality is indicative of relatively low consumption of plant foods in the Czech Republic – indeed, there is a high intake of animal fats, meat and meat products. These foods have an excessive share in the energy intake. In fact, in Czech Republic, there was an average intake of plant foods 1140 g/d (without fruits and vegetables) whereas the consumption of foods of animal origin amounted to 903.9 g/d in 2013. Many reports provide evidence that there is a negative correlation between meat and meat products and saturated fat intake and the amount of polyphenols in the diet [Martinez-Gonzalez & Martin-Calvo, 2013; Pericleous *et al*., 2014]. A low concentration of polyphenols in the food items that play an important role in the Czech dietary pattern (beer, potatoes) may also be of some significance in this relation. On the contrary, coffee and tea, which belong to the main sources of polyphenols in many European countries, are only a minor resource of polyphenols in the Czech Republic.

The analyses of polyphenol profiles tend to focus only on the content of flavonoids (*i.e*. a group which has been the longest known and best explored) and on the relation of flavonoids to the total content of other polyphenols. In the Czech

TABLE 4. Comparison of various national data related to the total consumption of plant polyphenols, their main food sources and prevailing subclasses of polyphenols.

Scenario of the study	The sum of polyphenols	Prevailing polyphenols/ sources/remarks
German National Nutrition survey II (1)	Total flavanol intake: 399 mg/d (women) 372 mg/d (men)	Main sources: pome fruits (27%), black tea (25%)
Habitual intake of some polyphenols in the European Union (2)	Czech Rep.: 181 mg/d max. Ireland: 793 mg/d min. Spain: 24 mg/d	Main sources: tea (62%), pome fruits (11%), berries (3%)
PREDIMED Study Intake and food sources of polyphenols in Spanish population at High CVD risk 55 – 80 years (3)	The mean polyphenol intake: 820±323 mg/d 443±218 mg/d flavonoids 304±156 mg/d phenolic acids	Prevailing hydroxycinnamates: 5-caffeoylquinic acid, Main sources: olives and olive oil
Finnish adults (4)	The mean total phenolics intake: 863 mg/d Phenolic acids, flavonoids: 415 mg/d	Dominant groups: phenolic acids – 75%, anthocyanidins – 10%, Main sources: coffee, cereals, berries
Polyphenols from fruits and vegetables (uncooked, France) – determined using Folin-Ciocalteu reagent(5)	No data	Main sources: apples and potatoes provide half of the total polyphenol intake, artichokes, parsley, Brussel sprouts, strawberries, apples, potatoes, onion
Polyphenol intakes in relation to European consumption of fruits and vegetables (6)	Anthocyanidins: 26 mg/d in Tajikistan 240 mg/d in Serbia Flavonols: 19 mg/d in Bulgaria 82 mg/d in Armenia Flavanols: 4 mg/d in Tajikistan 33 mg/d in Luxemburg	Intakes are highly variable (inter-individually)
Dietary intake and patterns of polyphenol consumption in Polish adult population (7)	Total phenolics intake: 1172 mg/d for men 1032 mg/d for women	Own polyphenol database was used Main sources: beverages, fruits, cereals, potatoes, white bread
Intakes of polyphenols in French cohort SU.VI.MAX, 45–60 y seniors (8)	98 polyphenols consumed in the amount above 1 mg/d; in total 1193±510 mg/d	Prevailing groups: hydroxycynnamates, proanthocyanidins Main sources: fruits and non-alcoholic beverages
Dietary intake of phenolics in Spain; institutionalized elderly population (73.2–76.8 y) (9)	Flavonoids: 62% (175–220 mg/d) Phenolic acids: 35.5% (99–128 mg/d)	Flavonoids and lignans intake was lower for those aged above 80 y. Main sources: wine, coffee, apples, oranges, white bread
US Adults, NHANES III(10)	Total flavonoids: 345 mg/d Flavan-3-ols: 192 mg/d	Main sources: wine, tea, beer, citrus fruits, apples
Consumption of phenolics by Brazilian population in 2008–2009 (11)	Average total intake: 460.2 mg/d 314 mg/d phenolic acids 139 mg/d flavonoids	Main sources: coffee, legumes; the consumption of fruits and vegetables is insufficient

(1)[Vogiatzoglou *et al*., 2014a], (2)[Vogiatzoglou *et al.*, 2014b],(3)[Tresserra-Rimbau *et al.*, 2013], (4)[Ovaskainen *et al.*, 2008], (5)[Brat *et al.*, 2006], (6)[Tennant *et al.*, 2014], (7)[Zujko *et al.*, 2012], (8)[Perez-Jimenez *et al.*, 2011], (9)[Gonzalez *et al.*, 2014], (10)[Bai *et al*., 2014], (11)[Correa *et al.*, 2015].

Republic, the proportion of flavonoids to the total content of polyphenols is rather low (212 mg/d : 426.6 mg/d *i.e.* 49.7%), thus reflecting a comparatively high intake of plant foods such as cereals, potatoes, and beer.

Regarding the distribution of various subclasses of polyphenols in the Czech diet, a relatively low intake of lignans and stilbenes is noteworthy. Recently, a strong negative association with the total mortality to lignans and stilbenes consumption has been determined in an epidemiological study [Tresserra-Rimbau *et al*., 2013]. Analogous inverse associations were reported in another studies, specifically for olives, olive oil, and red wine in relation to cardiovascular disease mortality [Chong *et al*., 2010; Mink *et al*., 2007] as well as for another foods such as berries, dark chocolate, and soy, *i.e.* for food items being significant sources of lignans and stilbenes [Zanotti *et al*., 2015]. Unfortunately, all these mentioned items are inadequately incorporated in the common Czech diet.

Currently, numerous authors have conducted epidemiological studies among thousands of healthy adults or seniors at cardiovascular risk. They assessed the effects of plant foods rich in polyphenols and reported that the consumption of green tea (source of catechins, flavan-3-ols), red wine and grapes (stilbenes), ginger and soybeans (curcumin and isoflavonoids), and colored berries (anthocyanins), provided several health benefits. These include anti-carcinogenic effects, improvement of endothelial functions and antioxidant status, modulation of inflammation, regulation of lipid metabolism, decrease of T2DM risk, and improved neurological disease treatment [Bai *et al*., 2014; Grosso *et al*., 2014].

At the present time a question arises and has been discussed: Could be targeted changes in the dietary pattern of a population, followed by an increasing intake of polyphenol and could be efforts made to introduce a dietary polyphenol recommendation desirable and beneficial to the public health? A new strategy for dietary pattern innovation that markets new, functional food enriched with some polyphenolics has been, to date, intended and debated [Ginter & Simko, 2012; Terao & Sies, 2014].

Nevertheless, molecular biological activity of polyphenols is difficult to be interpreted and elucidated. A large part of these compounds is metabolically destructed in the colon by intestinal microflora, and another part is quickly excreted from the body [Bohn, 2014; van Velyen *et al*., 2014]. Many intermediates of polyphenol metabolism that may be detected *in vivo* have heterogeneous and hardly definable structure. Their tissue concentration is usually extremely low [Velderrain-Rodriguey *et al*., 2014]. Moreover cooking causes a change of polyphenol structure, as well as a change in polyphenol linkage to the plant matter matrix, thereby deteriorating or decreasing polyphenol accessibility in a human body. The bioavailability and bioactivity of plant polyphenols in humans are to be further and more intensively studied [Palermo *et al*., 2014]. More accurate and interpretable research enabling the development of dietary recommendations regarding the intake of polyphenols is desirable [Balentine *et al*., 2015].

CONCLUSIONS

Foods of plant origin contain not only polyphenols, but also other numerous phytonutrients (fiber, betalains, carotenoids) and essential nutrients (vitamins and pro-vitamins, minerals). They may prove misleading, especially in the evaluation of epidemiological studies. The intensive examination of a specific proportion of polyphenols on the beneficial health effects of plant foods has to continue.

From the point of view of potential health benefits of plant foods and plant polyphenols a question emerges whether an intervention toward the quantity and structure of plants foods in favor of fruits (berries) and vegetables, as well as coffee and red grapes, could improve the spectrum of polyphenols in the diet and their health effect on the Czech population.

ACKNOWLEDGEMENTS

No external funding was used for this work. The study was conducted using common operating funds of the maternal institution.

CONFLICT OF INTEREST

Authors declare no conflict of interest.

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Submitted: 19 May 2016. Revised: 26 October and 3 November 2016. Accepted: 18 November 2016. Published on-line: 17 March 2017.