Polyphenols and dietary antioxidant potential, and their relationship with arterial hypertension: A cross-sectional study of the adult population in Poland (WOBASZ II)

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Conflict of interest

None declared

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Abstract

Background. Oxidative stress plays a key role in the development of most non-communicable diseases, including arterial hypertension (AH). Diet is the major source of exogenous antioxidants, which support the body in the elimination of excessive free radicals.

Objectives. To assess dietary total antioxidant potential (DTAP) and dietary polyphenol intake (DPI), and to determine the relationship between DTAP, DPI and hypertension in the Polish adult population; to indicate dietary sources of DTAP and DPI in participants with and without AH.

Material and methods. Within the frame of the National Multicenter Health Survey (WOBASZ II), a random sample of the whole Polish population aged 20 years and above was screened during the years 2013–2014. Dietary habits and blood pressure were assessed in 2,554 men and 3,136 women. Dietary total antioxidant potential and DPI were calculated according to the amount of food consumed by the participants combined with the antioxidant potential and polyphenol contents in foods.

Results. The mean DTAP was 12.36 mmol/day in men and 12.27 mmol/day in women, and DPI was 2069 mg/day and 1989 mg/day, respectively. The DTAP and DPI were associated with reduced odds of AH in the Polish population. After adjusting for confounding variables, higher DTAP (by 1 mmol/day) had reduced odds of AH by 1.3% in men and by 1.8% in women and higher DPI (by 100 mg/day) by 1.1% and by 2.2%, respectively. Regardless of sex and AH, the main sources of DTAP and DPI were beverages, especially coffee and tea (over 50%), fruit (12–24%) and vegetables (12–18%).

Conclusions. The intake of food with high antioxidant potential and rich in polyphenols was associated, slightly but independently of other factors, with a lower chance of hypertension in the adult Polish population. Irrespective of sex and AH, coffee and tea were the basic dietary sources of the antioxidants.

Key words: arterial hypertension, polyphenols, Polish population, dietary antioxidant potential

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Oxidative stress plays a key role in the development of most non-communicable diseases, including circulatory disorders and arterial hypertension (AH). It results from an imbalance between the action of free radicals and the antioxidant potential of the body. Diet is the major source of exogenous antioxidants, such as polyphenols, certain vitamins (C, E, β -carotene) and mineral components (Se, Zn, Fe, Mn, Cu) which support the body in the elimination of excessive free radicals through suitable enzymatic proteins.^{1,2}

A proper dietary supply of antioxidants exerts a beneficial effect on the lipid metabolism and endothelial function, reduces AH and decreases platelet aggregation, as well as seals and enhances vascular walls, leading to improvement in the peripheral circulation. However, the cardioprotective effect of polyphenols is based not only on the destruction of free radicals but also involves anti-aggregative properties and the ability to modulate numerous enzymatic pathways.^{2–6}

Up to now, neither recommended dietary antioxidant potential nor the total content of polyphenols that would exert a beneficial effect on health have been established in a daily food ration. However, publications are available on antioxidant potential and polyphenol intake in the diets of people living in various countries as well as on the relationship between these parameters and cardiovascular disease (CVD), mainly in terms of mortality risk and rate.^{7–15} At the same time, there are by far fewer reports concerning the relationship between antioxidant potential and polyphenol intake and AH.^{16–19} In Poland, AH is diagnosed in approx. 42.7% of adult inhabitants, posing a substantial health hazard and generating social and economic costs.²⁰

Taking into consideration the high prevalence of AH and the fact that oxidative stress is one of its promoting factors, it seems essential to investigate the consumption of bioactive substances that exhibit antioxidant properties in the Polish population.

The study objective was to:

- assess dietary total antioxidant potential (DTAP) and dietary polyphenol intake (DPI) in the Polish population in correlation with socioeconomic and health-related factors.
- evaluate the relationship between DTAP, DPI and AH;
- indicate and assess the differentiation of dietary sources of DTAP and DPI in participants with and without hypertension.

Material and methods

Study population

The study population involved a random sample of Polish residents aged 20 and older, examined in the years 2013–2014, as part of the Multicenter National Population Health Examination Survey (WOBASZ II). The project

was conducted by the Institute of Cardiology in Warszawa, Poland, in cooperation with 5 medical universities in Poland. A total of 15,120 people of both sexes were drawn from the Department of State Registry database run by the Ministry of Internal Affairs (PESEL register). The selection was made as a 3-stage sampling, stratified according to administrative units (voivodeships), type of urbanization (community size) and sex. This type of random sampling, as well as the sample size, allowed reliable assessment of dietary habits in the Polish population. Altogether, 6,170 respondents were recruited to the study, whereas reliable dietary recalls were obtained from 5,689 people (2,554 men and 3,135 women). The aims of WOBASZ II, its organization scheme, methodological details, methods of information collection, and measurements were presented in an earlier paper.²¹

Arterial blood pressure

The level of arterial blood pressure was measured using automatic devices UA-631 (A&D Company Ltd, Japan), approved by the Association for the Advancement of Medical Instrumentation (Arlington, USA). Blood pressure was measured 3 times at the right shoulder, in a sitting position, at 1-minute intervals. The mean value of blood pressure obtained from the 2nd and 3rd measurements was taken for the assessment. Study participants were diagnosed with hypertension when their systolic blood pressure (SBP) was ≥ 140 mm Hg and/or diastolic blood pressure (DBP) was ≥ 90 mm Hg, and/or they took hypotensive drugs.²¹

Dietary assessment

Dietary habits were assessed by means of a 24-hour dietary recall. The consumption of products that are the source of the antioxidant potential and polyphenols was calculated on the basis of daily food intake and food formulation. Food products were combined into groups, taking into consideration their type, origin and production technology. A total of 367 products and dishes, i.e., various beverages, vegetables and their products, fruit and jams, nuts and seeds, cereals, bread, and chocolate were included in the study.

Determination of antioxidant potential and polyphenols in food

The antioxidant potential and the content of polyphenols in food products typical of the Polish market were determined in the Department of Food Biotechnology, Medical University of Białystok, Poland. The analyses involved 3 independent samples of each product, purchased in retail, and in each case 2 versions were taken into consideration – the raw product and the product after culinary process. The distinction between raw and after culinary processes

is made due to the fact that culinary processes have an influence on investigated dietary antioxidants.²² Solid food samples were dried and extracted using a methanol-acetate mixture, and the extracts were analyzed. Direct measurements were performed in fluid samples. The antioxidant potential was determined using the ferric-reducing antioxidant potential (FRAP) method, according to Benzie and Strain,²³ and the polyphenol content (expressed as aglycones) was measured using the method according to Singleton and Rossi.²⁴ For each of the products, an average of 3 measurements was assumed for further analysis. In the case of the very few products that were not subjected to laboratory analysis, the antioxidant potential and polyphenol content were obtained from the available database.^{25,26} For each study participant, DTAP and DPI were determined taking into consideration the consumption of food products and the level of their antioxidant potential and polyphenol content.

Statistical methods

Methods of descriptive statistics were applied to describe continuous variables (mean, standard deviation (SD), quartiles) and the percentages of the respective values were used for categorized variables. Parametric tests (analysis of variance (ANOVA) and Student's *t*-test) and non-parametric tests (Mann–Whitney–Wilcoxon test and χ^2 test) were used to compare the groups, depending on whether they fulfil the assumption of normal distribution or not.

The analysis of covariance (generalized linear model (GLM) procedure) with age and season adjustment was applied to determine the mean DTAP and DPI in groups with different socioeconomic and health status. The association between DTAP, DPI and AH was assessed by logistic regression analyses (LOGISTIC procedure). Odds ratios (ORs) with the corresponding 95% confidence intervals (CIs) were calculated for unadjusted and adjusted models.

The level of significance for bilateral tests was considered to be at $p < 0.05$. The statistical analysis was performed with the statistical package SAS v. 9.2 (SAS Institute, Cary, USA).

Results

The mean total antioxidant potential of a daily food ration in the adult population of Poland (age- and season-adjusted) was 12.36 mmol/day in the group of men and 12.27 mmol/day in the group of women, whereas the total content of polyphenols was found to be 2,069 mg/day and 1,989 mg/day, respectively (Table 1, 2). The levels of the parameters studied depended on socioeconomic and health-related factors, such as age, marital status and paid employment in both sexes, and education only in women. Of the health-related factors, DTAP was determined by health self-assessment in both sexes, CVD in men and

AH in women. In turn, DPI in men was influenced by CVD, and in women by AH, diabetes and health self-assessment (Table 1, 2).

The analysis of the relationship between DTAP, DPI and AH, having eliminated other factors, showed a significant decrease in the contribution of women with AH along with an increase in the quartile of the antioxidant potential (45% in 1st quartile vs 38% in 4th quartile) and polyphenols (45% vs 39%, respectively). In the group of men, the tendencies were similar, although statistically insignificant (Table 3).

The odds of AH with the antioxidant potential increased by 1 mmol/day was lower by 1.1% in the group of men and by 2.3% among women, and after adjustment for confounding variables (listed below Table 3), lower by 1.3% and 1.8%, respectively, in the sex groups. Similar results were obtained for polyphenols. The increase in the polyphenol supply by 100 mg/day, lowered the odds of AH by 0.8% in men and by 2.4% in women, and after adjustment for other AH-affecting factors, by 1.1% and 2.2%, respectively (Table 4).

Tables 5 and 6 present the contribution of food groups (beverages, vegetables, fruit, cereals, nuts and seeds, chocolate, and cacao) to DTAP and DPI intakes. Among adult residents of Poland, irrespective of sex and AH, beverages, especially tea and coffee, appeared to be the basic food sources of antioxidant potential and polyphenols. Over 50% of DTAP and more than 40% of DPI were obtained from beverages. Fruit provided approx. 12–18% of the antioxidant potential and 17–24% of polyphenols, and vegetables 14–18% and 12–14%, respectively, depending on sex and AH. Further places were occupied by cereal products, nuts and seeds, chocolate, and cacao. Of fruit, apples and strawberries, and of vegetables, potatoes and cabbage were a significant source of DTAP and DPI, and beetroots of DTAP only.

Some differences were found in dietary sources of DTAP and DPI between people with and without AH. Among men with AH, the contribution of DTAP and DPI from fruit was higher whereas from cereal products, nuts and seeds, chocolate and cacao, it was lower. The diet of women with AH was characterized by a lower contribution of DTAP and DPI obtained from beverages, cereal products, chocolate, and cacao. The quantities provided by vegetables and fruit were similar, irrespective of AH (Table 5, 6).

Discussion

The imbalance between pro- and antioxidant processes and the accumulation of reactive oxygen species (ROS) in the body which initiate cellular damage promote non-communicable diseases. A significant correlation was found between the dietary antioxidant potential and the antioxidant status of blood serum.²⁷ Thus, proper nutrition provided by dietary components which act as antioxidants can prevent the harmful effects of oxidative stress.

Table 1. Dietary total antioxidant potential (mmol/day) of Polish population according to socioeconomic and health-related factors (adjusted for age and season)

Variable	Men				Women			
	N ¹	mean	CI	p-value	N ¹	mean	CI	p-value
Total population	2,554	12.36	12.08–12.65		3,135	12.27	12.02–12.53	
Age group [years]								
20–35	574	11.69	11.08–12.30		635	11.77	11.21–12.33	
36–50	706	13.43	12.88–13.98		832	13.16	12.67–13.65	
50–65	783	13.01	12.49–13.53		1,004	12.93	12.48–13.38	
≥65	491	10.64	9.98–11.30		664	10.60	10.05–11.15	<0.0001
Educational level								
low	1,135	12.15	11.69–12.60		1,136	11.54	11.09–12.00	
medium	938	12.68	12.20–13.17		1,200	12.49	12.08–12.90	
high	478	12.30	11.61–13.00	0.2898	796	12.96	12.42–13.50	0.0005
Marital status								
married	1,792	12.78	12.43–13.13		2,003	12.54	12.22–12.86	
single	761	11.42	10.87–11.98	<0.0001	1,133	11.78	11.35–12.20	0.0049
Occupational activity								
yes	1,525	12.84	12.44–13.25		1,453	12.64	12.24–13.03	
no	1,028	11.68	11.18–12.19	0.0011	1,681	11.94	11.58–12.31	0.0178
CVD								
diagnosed with CVD	494	11.06	10.35–11.77		664	12.15	11.56–12.75	
without history of CVD	2,060	12.69	12.36–13.02	<0.0001	2,492	12.29	12.00–12.58	0.689
Diabetes								
diagnosed/glucose ≥7 mmol/L	290	11.80	10.89–12.71		297	11.50	10.64–12.35	
fasting glucose <7 mmol/L	2,155	12.52	12.20–12.85	0.1463	2,685	12.36	12.08–12.64	0.0625
Blood pressure								
≥140/90 mm Hg/medication	1,249	12.13	11.70–12.57		1,292	11.79	11.35–12.23	
<140/90 mm Hg	1,271	12.61	12.18–13.05	0.1465	1,807	12.59	12.23–12.95	0.0118
Self-assessment of health status								
very good, good	1,733	12.67	12.30–13.03		2,019	12.66	12.33–12.99	
average	662	11.64	11.03–12.25	0.0237	916	11.79	11.29–12.28	<0.0001
bad, very bad	101	12.12	10.63–13.61		148	9.83	8.63–11.03	

¹ Differences in the size of groups derive from the lack of data for some people; CVD – cardiovascular disease; CI – confidence interval.

Table 2. Dietary polyphenol intake (mg/day) of Polish population according to socioeconomic and health-related factors (adjusted for age and season)

Variable	Men				Women			
	N ¹	mean	CI	p-value	N ¹	mean	CI	p-value
Total population	2,554	2,069	2,035–2,104		3,135	1,989	1,958–2,020	
Age group [years]								
20–35	574	2,007	1,930–2,083	<0.0001	635	1,930	1,865–1,996	<0.0001
36–50	706	2,189	2,120–2,258		832	2,098	2,041–2,155	
50–65	783	2,161	2,095–2,226		1,004	2,074	2,022–2,126	
≥65	491	1,837	1,754–1,920		664	1,771	1,708–1,835	
Educational level								
low	1,135	2,064	2,007–2,121	0.8672	1,136	1,921	1,868–1,974	0.0108
medium	938	2,085	2,024–2,146		1,200	2,013	1,965–2,061	
high	478	2,062	1,976–2,149		796	2,043	1,980–2,106	
Marital status								
married	1,792	2,114	2,070–2,159	0.0008	2,003	2,027	1,990–2,065	0.0004
single	761	1,971	1,901–2,040		1,133	1,915	1,866–1,965	
Occupational activity								
yes	1,525	2,133	2,082–2,183	0.0007	1,453	2,032	1,986–2,079	0.0129
no	1,028	1,982	1,919–2,046		1,681	1,948	1,905–1,991	
CVD								
diagnosed with CVD	494	1,948	1,859–2,037	0.003	664	1,935	1,865–2,004	0.1008
without history of CVD	2,060	2,101	2,060–2,143		2,492	2,001	1,967–2,034	
Diabetes								
diagnosed/glucose ≥7 mmol/L	290	2,001	1,888–2,114	0.1668	297	1,863	1,764–1,962	0.0094
fasting glucose <7 mmol/L	2,155	2,086	2,046–2,126		2,685	2,002	1,971–2,034	
Blood pressure								
≥140/90 mm Hg/medication	1,249	2,048	1,993–2,103	0.2821	1,292	1,906	1,854–1,957	0.0002
<140/90 mm Hg	1,271	2,093	2,038–2,147		1,807	2,045	2,002–2,087	
Self-assessment of health status								
very good, good	1,733	2,093	2,047–2,139	0.2876	2,019	2,038	2,000–2,076	<0.0001
average	662	2,019	1,942–2,095		916	1,928	1,870–1,986	
bad, very bad	101	2,064	1,877–2,251		148	1,692	1,552–1,832	

¹ Differences in the size of groups derive from the lack of data for some people; CVD – cardiovascular disease; CI – confidence interval.

Table 3. Prevalence of arterial hypertension by quartiles of dietary total antioxidant potential (DTAP) and dietary polyphenol intake (DPI)

Parameters	Quartile 1	Quartile 2	Quartile 3	Quartile 4	p-value
Men					
DTAP [mmol/day] mean $\pm$ SD range	5.22 $\pm$ 1.75 0.47–7.70	9.43 $\pm$ 1.02 7.71–11.15	13.16 $\pm$ 1.20 11.16–15.38	21.67 $\pm$ 8.52 15.39–95.37	
Arterial hypertension [%] ¹	50.15	51.56	50.98	46.24	0.1489
DPI [mg/day] mean $\pm$ SD range	1,033 $\pm$ 285 174–1,409	1,694 $\pm$ 158 1,410–1,956	2,252 $\pm$ 173 1,957–2,559	3,305 $\pm$ 800 2,560–9,047	
Arterial hypertension [%] ¹	49.64	50.91	51.91	46.42	0.1511
Women					
DTAP [mmol/day] mean $\pm$ SD range	5.52 $\pm$ 1.77 0.32–7.91	9.72 $\pm$ 1.00 7.94–11.35	13.14 $\pm$ 1.11 11.35–15.19	20.68 $\pm$ 9.07 15.20–191.82	
Arterial hypertension [%] ¹	45.17	42.88	41.11	38.12	0.0073
DPI [mg/day] mean $\pm$ SD range	1,035 $\pm$ 273 140–1,414	1,665 $\pm$ 138 1,415–1,903	2,156 $\pm$ 155 1,904–2,441	3,093 $\pm$ 703 2,442–8,793	
Arterial hypertension [%] ¹	45.37	43.68	39.40	38.82	0.0030

¹ Adjusted for age, BMI, smoking and physical activity; BMI – body mass index; SD – standard deviation.

Table 4. Multivariate odds ratio (OR) and 95% confidence intervals (95% CI) for arterial hypertension by total dietary total antioxidant potential (DTAP) (per 1 mmol/day) and dietary polyphenol intake (DPI) (per 100 mg/day)

Variables	Men			Women		
	OR	95% CI	p-value	OR	95% CI	p-value
DTAP unadjusted	0.989	0.979–0.999	0.0480	0.977	0.966–0.988	<0.0001
adjusted ¹	0.987	0.976–0.998	0.0248	0.982	0.970–0.995	0.0051
DPI unadjusted	0.992	0.983–0.999	0.0474	0.976	0.967–0.985	<0.0001
adjusted ¹	0.989	0.981–0.998	0.0194	0.978	0.969–0.988	<0.0001

¹ Adjusted for age, body mass index (BMI), smoking and physical activity.

The results indicate that the mean total antioxidant potential in the diet of the adult Polish population was 12.36 mmol/day in the group of men and 12.27 mmol/day in the group of women, whereas the polyphenol content amounted to 2,069 mg/day and 1,989 mg/day, respectively. However, the comparison of our results with the levels of DTAP and DPI in other populations is very difficult due to, first of all, the use of various methods to determine these substances. The antioxidant potential can be measured, e.g., according to the FRAP or oxygen radical absorbance capacity (ORAC) method. The polyphenols exist as aglycones (the free form) or glycosides (occurring as compounds with sugars, most commonly with glucose).

Since the recommended level of DTAP and DPI has not been established, it is difficult to assess whether the intake of bioactive components of adult residents of Poland meets recommendations.

There are very few studies, particularly conducted in Polish centers, the results of which can be directly compared to our findings. The available data obtained with the ORAC method indicates that DTAP was found at the level of 8,300–10,000 μ molTE/day among

the population of Wrocław, Poland.^{11,14} Similar results were noted in the European Prospective Investigation into Cancer and Nutrition (EPIC) project, in which DTAP in the Spanish and Greek population was in the range of 11,000–12,000 μ molTE/day.^{8,9} In women living in Sweden, DTAP amounted to 12,127 μ molTE/day.⁷ All these values were consistent with the recommendations of Priori et al.,²⁸ who were the only investigators to assess that DTAP has to be at the level of 3,000–5,000 μ molTE/day to ensure the proper antioxidant capacity of tissues and blood.

In the male population of Sweden, DTAP determined with the FRAP method was approx. 22 mmol/day, and was higher by over 60% than in the Polish population.²⁹

The mean estimates of the intake of polyphenols (approx. 2,000 mg/person/day) were comparable to those reported from Kraków, Poland (1,757 mg),¹⁵ but higher than in Finland (863 mg),¹³ Japan (1,492 mg),¹² France (1,193 mg),³⁰ and Spain (820 mg).¹⁰

However, irrespective of the consumption volume, dietary sources of DTAP and DPI differed between the respective countries. The intake of antioxidants in the Polish

Table 5. Contributions of food categories to dietary total antioxidant potential (DTAP) in persons with and without arterial hypertension (AH)

Men			
Food categories	with AH (N = 1,249)	without AH (N = 1,271)	p-value
Beverages	6.52 mmol/day (54.0%): coffee (27.8%); tea (22.7%); alcohol (1.6%)	6.90 mmol/day (54.5%): coffee (30.9%); tea (20.1%); alcohol (1.4%)	0.1271
Vegetables	2.20 mmol/day (18.2%): potato (7.1%); beetroot (3.0%); cabbage (2.2%); tomato (1.2%); broccoli and cauliflower (1.1%)	2.25 mmol/day (17.8%): potato (6.6%); beetroot (3.6%); cabbage (2.2%); tomato (1.1%); broccoli and cauliflower (0.9%)	0.9603
Fruit	1.85 mmol/day (15.3%): apples (4.8%); strawberries (2.1%); grapes (1.7%); plums (1.4%); citrus fruits (0.8%); cherries (0.8%)	1.55 mmol/day (12.2%): apples (4.0%); strawberries (1.3%); grapes (1.1%); plums (0.9%); citrus fruits (0.7%); cherries (0.8%)	0.0050
Cereals	0.56 mmol/day (4.6%): mixed bread (1.9%); wheat bread (0.9%); rye bread (0.9%)	0.61 mmol/day (4.6%): mixed bread (1.9%); wheat bread (1.0%); rye bread (0.7%)	0.0002
Nuts and seeds	0.32 mmol/day (2.7%)	0.60 mmol/day (4.8%)	0.0295
Chocolate and cocoa	0.29 mmol/day (2.4%)	0.38 mmol/day (3.0%)	0.0002
Women			
Food categories	with AH (N = 1,292)	without AH (N = 1,807)	p-value
Beverages	6.49 mmol/day (55.8%): coffee (32.2%); tea (22.0%); alcohol (0.2%)	7.38 mmol/day (58.2%): coffee (36.4%); tea (19.4%); alcohol (0.3%)	0.0001
Vegetables	1.75 mmol/day (15.0%): potato (5.2%); beetroot (2.4%); cabbage (1.9%); tomato (1.2%); broccoli and cauliflower (1.1%)	1.82 mmol/day (14.4%): potato (4.6%); beetroot (2.8%); cabbage (1.8%); tomato (1.0%); broccoli and cauliflower (1.2%)	0.4879
Fruit	2.12 mmol/day (18.2%): apples (4.9%); strawberries (2.8%); grapes (2.2%); plums (1.6%); citrus fruits (1.0%)	1.98 mmol/day (15.6%): apples (4.5%); strawberries (2.2%); grapes (1.7%); plums (1.1%); citrus fruits (1.1%)	0.9210
Cereals	0.40 mmol/day (3.4%): mixed bread (1.0%); wheat bread (0.7%); rye bread (0.7%)	0.43 mmol/day (3.4%): mixed bread (0.9%); wheat bread (0.7%); rye bread (0.7%)	0.0001
Nuts and seeds	0.39 mmol/day (3.3%)	0.42 mmol/day (3.3%)	0.1207
Chocolate and cocoa	0.24 mmol/day (2.1%)	0.36 mmol/day (2.8%)	0.0001

Table 6. Contributions of food categories to dietary polyphenol intake (DPI) in persons with and without arterial hypertension (AH)

Men			
Food categories	with AH (N = 1,249)	without AH (N = 1,271)	p-value
Beverages	818.0 mg/day (40.2%): coffee (18.8%); tea (18.2%); alcohol (1.2%)	860.0 mg/day (40.8%): coffee (22.3%); tea (16.1%); alcohol (1.0%)	0.2013
Vegetables	288.2 mg/day (14.2%): potato (6.7%); cabbage (1.5%); tomato (1.6%)	293.2 mg/day (13.9%): potato (6.3%); cabbage (1.5%); tomato (1.4%)	0.5790
Fruit	409.0 mg/day (20.1%): apples (10.2%); plums (2.4%); strawberries (1.3%); bananas (1.2%); currant (0.9%); grapes (0.9%)	359.5 mg/day (17.1%): apples (8.6%); plums (1.5%); strawberries (0.8%); bananas (1.7%); currant (0.6%); grapes (0.6%)	0.0010
Cereals	382.0 mg/day (18.8%): mixed bread (8.4%); wheat bread (3.9%); rye bread (3.7%)	415.8 mg/day (19.7%): mixed bread (8.5%); wheat bread (4.4%); rye bread (3.1%)	0.003
Nuts and seeds	16.0 mg/day (0.8%)	28.8 mg/day (1.4%)	0.0287
Chocolate and cocoa	56.0 mg/day (2.7%)	74.5 mg/day (3.5%)	0.0002
Women			
Food categories	with AH (N = 1,292)	without AH (N = 1,807)	p-value
Beverages	813.7 mg/day (43.1%): coffee (23.9%); tea (18.1%); alcohol (0.1%)	917.9 mg/day (44.6%): coffee (27.0%); tea (16.0%); alcohol (0.2%)	0.0001
Vegetables	234.7 mg/day (12.4%): potato (5.1%); cabbage (1.2%); tomato (1.6%)	242.0 mg/day (11.8%): potato (4.5%); cabbage (1.3%); tomato (1.4%)	0.6405
Fruit	456.8 mg/day (24.2%): apples (10.8%); plums (2.8%); strawberries (1.7%); bananas (1.3%); currant (1.2%); grapes (1.2%); peaches (1.7%)	440.6 mg/day (21.4%): apples (9.9%); plums (1.9%); strawberries (1.4%); bananas (2.0%); currant (2.0%); grapes (0.9%); peaches (0.9%)	0.8030
Cereals	261.3 mg/day (13.8%): mixed bread (4.7%); wheat bread (3.2%); rye bread (3.1%)	285.0 mg/day (13.9%): mixed bread (4.1%); wheat bread (3.1%); rye bread (3.0%)	0.0010
Nuts and seeds	19.7 mg/day (1.0%)	22.3 mg/day (1.1%)	0.1193
Chocolate and cocoa	47.3 mg/day (2.5%)	75.4 mg/day (3.7%)	0.0001

population, noted both in the current research and previously,^{14,15,31} as well as in Japan¹² was related mainly to the consumption of coffee and tea, and then vegetables and fruit, whereas in Finland it was related to the intake of coffee and cereal products,¹³ in Spain to coffee, fruit and olive oil,¹⁰ and in Sweden and Greece to vegetables and fruit.^{7,9} These results indicate a difference in the structure of dietary sources of DTAP and DPI between people with and without AH. Respondents with AH showed lower consumption of coffee, alcohol, cereal products, chocolate, and cacao, and therefore of fewer bioactive substances derived from those products. Men with AH also consumed more fruit and fewer nuts and seeds. However, the cross-sectional character of the WOBASZ II does not allow for any cause-and-effect conclusions and it is therefore unknown whether their diet underwent modification due to the disease or the people with AH had these dietary habits earlier.

There has been a growing interest in the potential involvement of reactive oxygen forms in the search for AH causes. However, the metabolic mechanisms underlying this relationship still remain insufficiently explained, despite numerous studies. Obviously, the imbalance between free oxygen radicals and antioxidant factors (also from food) contributes to endothelial damage and enhances inflammatory reactions, which have been recently reported to be responsible for AH.³²

Observational and experimental studies confirm that diets with high antioxidant potential and high polyphenol content contribute to AH reduction.^{5,18} However, most of these projects assessed these correlations only at the level of the respective products rich in polyphenols (e.g., cacao, fruit and vegetables, tea, olive oil, etc.),¹ and only few took into consideration total dietary antioxidant potential and total polyphenol intake.

The current results seem to prove a slight but independent relationship between the dietary antioxidants studied and AH among adult Polish residents. Even less advanced statistical analyses showed lower mean values of DTAP and DPI in women with AH than in those without this condition. A significant reduction was also noted in the involvement of women with AH along with the increased DTAP and DPI quartile, even after adjustment for confounding variables. The tendencies were similar in men, although statistically insignificant.

However, more advanced analyses revealed that with DTAP increased by 1 mmol/day or DPI by 100 mg/day, the odds of AH in both sexes decreased by approx. 1–2%, even after correcting for confounding variables.

Our data is comparable to the results obtained in few studies which took into consideration total antioxidant activity and total dietary polyphenol intake. However, it should be added that in some of them the levels of biomarkers excreted with urine were referred to as the variables reflecting their dietary intake.

For instance, in São Paulo, Brazil, an inverse relation was observed between total polyphenol content and

AH, but also with regard to the 2nd quartile, OR = 0.36 (CI = 0.19–0.69). Also, significant and linear correlations were noted between certain classes of polyphenols, such as tyrosols, alkylphenols, lignans, and stilbenes, which unfortunately were not evaluated in our study.¹⁶ However, in the PREvencion con Dieta MEDiterranea (PREDIMED) study it was estimated that in individuals with high risk of cardiovascular diseases, the risk of AH in the highest quartile of urinary polyphenols was 0.64 (CI = 0.45–0.92), as compared to the lowest quartile, after eliminating other factors. Also, the values of SBP and DBP were inversely correlated with polyphenol excretion.¹⁹ Clinical-control examinations were performed as part of the same project. In some individuals, the diet was enriched with polyphenols by adding olive oil or nuts. After a year, in individuals with dietary intervention, a significant increase was observed in urinary polyphenols and serum nitric oxide, which was associated with a decrease in SBP and DBP.³³

It should be emphasized that coffee is the main source of DTAP and DPI in the Polish population (including in individuals with AH). Coffee provides not only antioxidants but also caffeine, which has been reported to be linked with AH, vascular resistance and endothelial dysfunction.³⁴ On the other hand, as indicated by meta-analysis, in individuals with AH, caffeine increases arterial blood pressure for only 3 h, and no relationship has been confirmed between long-term coffee drinking and elevated AH or increased risk of CVD in AH patients.³⁵ However, a study involving Kraków residents revealed that the risk of AH was lower in individuals declaring moderate consumption of coffee (3–4 cups/daily), and that only higher coffee intake did not protect against AH.³⁶

Considerable quantities of the bioactive substances analyzed in the current study were also obtained from tea. According to the available data, tea reduces arterial blood pressure.^{17,37} Unfortunately, the data was obtained from studies performed on a very small number of patients in a short period of time, which does not warrant conclusions regarding the long-term advantages of drinking large amounts of tea.¹⁷

Considering the inconclusive data on the effect of coffee and tea on AH, it seems that the consumption of fruit and vegetables as the source of DTAP and DPI would be more beneficial for the Polish population.

Some respondents involved in the WOBASZ II took dietary supplements, an additional source of antioxidant potential, which were not taken into consideration in the analysis. However, the estimated involvement of study participants enriching their diet with vitamins and minerals was 12.3% and 15.7%, respectively, in the group with and without AH, and was not statistically differentiated (unpublished data). Therefore, it seems that the supplementation could not significantly modify the relationship between DTAP, DPI and AH.

The advantages of the presented study include:

– results based on a representative sample of the adult

Polish population, in a large number, with the use of standardized methods;

- assessment of individual dietary habits, recommended for the determination of the relationship between nutrition and health in epidemiological studies;
- measurement of the antioxidant potential and polyphenols in reconstituted food samples typical of the Polish market, taking into account culinary processing;
- the use of databases obtained from other countries generates errors due to the lack of regional dishes and because bioactive substances are determined in products from other climate and soil zones. However, culinary processes differently affect both the antioxidant potential and polyphenol content.

Limitations of the study

The limitations of the current study are as follows:

- not very high responsiveness of the respondents in the WOBASZ II study is typical of other currently performed European epidemiological studies. This problem was discussed in previous WOBASZ-related publications.^{21,38} Additionally, statistical analyses were performed, confirming the similarity of distribution of people in age groups throughout the Polish population and in the study sample, which indicates the representativeness of the WOBASZ II study;
- arterial blood pressure was taken 3 times, but only during 1 visit;
- single assessment of dietary habits by means of 24-hour-recall is acceptable in large epidemiological studies, but its repetition could likely reduce the inter-individual variation of nutrition.

Conclusions

The intake of food with high antioxidant potential and rich in polyphenols was associated, slightly but independently of other factors, with a lower chance of hypertension in the adult Polish population. Higher DTAP (by 1 mmol/day) or higher DPI (by 100 mg/day) had reduced the odds of AH by approx. 1–2%, even after correcting for confounding variables.

Coffee and tea were the basic dietary sources of the antioxidants studied, irrespective of sex and AH. Taking into consideration the inconclusive data concerning the effects of these beverages on AH, vegetables and fruit should be recommended as a more beneficial source of DTAP and DPI for the Polish population.

The results of the project can help formulate recommendations concerning polyphenol content and antioxidant potential of a daily food ration.

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