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Contents of polyphenols in fruit and vegetables

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Abstract

The work is an attempt at a model presentation, using a new multi-criteria mathematical method called the analytical hierarchy process, of polyphenol supply to human organisms from fruit and vegetables. On this basis, plant raw materials which supply polyphenols to the organism to the greatest extent and thus contribute to an improvement in health state of people in Poland were identified.

Keywords: Polyphenols; Fruit; Vegetables; Health effects; Analytic hierarchy process

1. Introduction

There has been a growing interest in food components which may inhibit or interrupt the oxidation process and are capable of counterbalancing free radical activities that cause cell injuries leading to neoplastic lesions, inflammatory conditions or negative changes in blood vessels. Increasing numbers of research results confirm that injuries due to an excessive production of free oxygen radicals occur in many common pathological states, such as cardiovascular diseases, some prenatal complications, neoplastic diseases, inflammatory states (e.g., rheumatoid arthritis), cataract, Parkinson's disease, Alzheimer's disease or ageing of the organism (Darlington & Stone, 2001; Szczypka, 1997). The best way to prevent these diseases is consumption of an optimal diet containing natural antioxidants. Currently, researchers have been discovering the importance of polyphenol compounds present in plants, which not long ago were considered unnecessary for the human diet. There are many proofs that the compounds are efficient antioxidants, stronger than antioxidant vitamins (Bravo, 1998; Shrikhande & Franch, 1974). A common feature of polyphenols, particularly those whose hydroxyl groups occur in the *ortho*- or *para*-position, is ease of entry into redox reactions. Phenolic compounds are able to carry protons and electrons, which means that they easily undergo oxidation (Shahidi, Janitha, & Wanasundara, 1992). *Flavonoids* are one of the better-known groups of polyphenols. They are most common in edible plant products, particularly fruits and vegetables (excluding algae and mushrooms) (Bravo, 1998). Food products abundant in flavonoid compounds are green-leafed, yellow and red vegetables (e.g., onion, cabbage, broccoli, cauliflower, Brussels sprouts, pulse seeds, tomatoes, and peppers), fruit (e.g., grapefruits, oranges, berries, red and black currants, dark grapes, apples and aronia) (Bengoechea, Sancho, & Bartolome, 1997; Buren, Vos, & Pilnik, 1976; Lu & Foo, 1997; Oleszek, Lee, & Jaworski, 1988), but also tea (especially green tea) (Hojden, 2000; Perucka, 2001) and red wine (Pelegrinin, Simonetti, & Gordana, 2000; Vinson & Hontz, 1995).

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Many studies show that natural antioxidants present in plants have positive effects upon the cardiovascular system. They prevent a negative phenomenon of thrombocyte sealing and oxidation of the LDL cholesterol fraction and other lipids present in blood, which accelerate sclerotic processes (Heinonen, Lehtonen, & Hopia, 1998). Moreover, they sustain the elasticity, integrity and blood vessel wall resistance to injury (Horbowicz, 2000). The phenomenon has been observed in the Mediterranean area, as the so-called "French paradox" where, despite a considerable proportion of fat in the dwellers' diets, mortality caused by cardiovascular system diseases is much lower than in other countries. The fact is ascribed to a large dietary proportion of fruits, vegetables, and red wine (Fogliano, Verde, & Randazzo, et al., 1999; Hurtado, Caldu, & Gonzalo, et al., 1997; Soleas, Dam, & Carey, et al., 1997; Zduńczyk, 1999). Moreover, the natural antioxidants can form complexes with metals, namely, iron, copper, zinc, lead, and antimony, and become excreted from the organism (Ślężko, 1996).

It has been considered that no less than 1–2 g of polyphenols (including flavonoids) should be consumed daily (Świderski, 2000) whereas, in an average diet consumed in Poland, they are estimated to be 0.032 g daily (Zduńczyk, 1999). By comparison, in Finland, they are only 0.003 g daily, in Japan 0.068 g daily and, in the USA 1.1 g/daily (Bravo, 1998; Nijveldt, 2000).

This work aimed at determining total polyphenol contents in selected fruits and vegetables, available in the Polish market, and then selecting these with the highest contents of the studied compounds. Moreover, the work attempted to find the raw materials, and forms in which they should be consumed, which best contribute to improvement of health of the people of Poland.

2. Material and methods

2.1. Materials

The research material comprised nine fruit species and nine vegetable species, purchased in summer, 2002, in shops in Krakow. The fruit included: white grapes, pink grapes, plums, Węgierka c.v. pink grapefruits, oranges, kiwi fruit, apples, Gala c.v., nectarines and European elder fruit. Grapefruits and oranges originated from Spain, kiwi fruit from New Zealand, grapes and nectarines from Italy, while apples, plums and European elder came from Poland. The following vegetables were selected for the studies: tomatoes "Krzeszowicki" c.v., zucchini, Italian cabbage, carrots, parsley root, celery root, onion, broccoli and Brussels sprouts–all were grown in Poland.

2.2. Methods

Total polyphenol contents and dry mass level in the studied material were determined by standard methods of AOAC (1995), whereas the Analytic Hierarchy Process (AHP) (Saaty, 1990) was used for the result elaboration.

2.2.1. The essence of the analytic hierarchy process

The analytic hierarchy process (AHP) has been one of the fastest developing mathematical methods over recent years used for solving multi-criteria decision problems. AHP is a general theory of measurement, combining some concepts of mathematics and psychology. It differs from the other multi-criteria methods in two aspects. The first is building a problem structure as a hierarchy of the overall goal, criteria and intermediate aims, attributes and alternative decisions. The overall goal is placed on top of the hierarchy, while alternative decisions form its lowest level. The significance and preferences of individual decision elements are joined in pairs with reference to the element immediately above in the hierarchy.

The second aspect involves establishing a relative evaluation (priority) scale for comparing quantitative and qualitative notions, in order to form opinion, treating the real world in terms of understanding, measurement and proportion. It is done through direct comparison of the level of importance and preference of each pair of decision elements without using physical units. Thus AHP is used for the analysis of both quantitative and qualitative variables. The result of comparison is an additive model, constructed in the quotient scale, which describes the decision maker's preferences. The model has been called a priority function. The alternative decision, corresponding to the highest total value of priority function, has been considered the best and is recommended for practical application (Adamus & Gręda, 2002; Adamus & Zając, 2001).

3. Results and discussion

The obtained results indicate diversified polyphenol contents, depending on many factors, including, inter alia, the raw material species. The highest concentration of polyphenols 1540 mg/100 g was found in the European elder fruit, the lowest in nectarines (57 mg/100 g) (Table 1). Among the vegetables, broccoli was characterized by the largest contents of these compounds (290 mg/100 g), whereas the lowest concentration was detected in zucchini, i.e., only 38 mg/100 g of product (Table 2).

The available literature provides no information about polyphenol contents in broccoli, carrot, parsley or zucchini; no such data were found for either kiwi fruit

Table 1
Total polyphenol contents in studied fruit

Material	Mean dry mass content (%)	Mean polyphenol content in fresh mass (mg/100 g)	Mean polyphenol content in dry mass (mg/100 g)	Range of polyphenol content in dry mass (mg/100 g)
White grapes	11.98	95	793	771–816
Pink grapes	13.62	93	683	660–707
Plum"Węgierka" c.v.	12.51	200	1599	1589–1609
Pink grapefruit	10.48	425	4057	3839–4300
Orange	14.85	217	1461	1407–15193
Kiwi fruit	12.57	273	2169	2120–2219
Apples"Gala"c.v.	13.69	132	964	905–1030
European elder	23.77	1540	6480	6105–6905
Nectarine	10.23	57	557	544–572

Table 2
Total polyphenol contents in studied vegetables

Material	Mean dry mass content (%)	Mean polyphenol content in fresh mass (mg/100 g)	Mean polyphenol content in dry mass (mg/100 g)	Range of polyphenol content in dry mass (mg/100 g)
Zucchini	4.47	38	850	805–900
Tomato	4.16	62	1490	1422–1564
Carrot	10.52	156	1485	1400–1582
Celery root	13.3	59	445	439–452
Italian cabbage	6.67	108	1620	1573–1670
Onion	11.2	150	1339	1221–1483
Parsley root	22.1	67	303	273–340
Broccoli	15.1	290	1924	1621–2363
Brussels sprouts	19.5	91	468	476–460

or nectarines. The results obtained for the other studied raw materials corroborated the published data (Borowska, Zadernowski, & Wazbinska, et al., 2000; Bravo, 1998). In order to conduct a statistical analysis, levels of polyphenols determined in fruit and vegetables were converted into dry mass. The results obtained for fruit did not cause a change of hierarchy for individual raw materials concerning their polyphenol contents. Similarly, as in case of conversion into fresh mass, the largest dry mass concentrations of polyphenols were found in European elder fruit (6400 mg/100 g) and the lowest in nectarines (557 mg/100 g) (Table 3). Analysis of results concerning polyphenol contents in vegetables, in conversion to raw material fresh mass, revealed considerable differences in the hierarchy. It resulted both from fluctuations in polyphenol contents and fluctuations in dry mass contents ranging from 4.5% for zucchini to 22% for parsley root. Broccoli proved the raw material with the largest content of polyphenols (923 mg/100 g dry mass) whereas the smallest amount, i.e., 303 mg/100 g dry mass, was detected in parsley root (Table 4).

Polyphenol supply for the human organism is affected, not only by their concentrations in the raw material, but also the amount of consumption. Besides, these compounds are more active in human organism in the presence of vitamin C. It is also thought that polyphenols present in fruit and sweet vegetables have stronger effects because saccharides enhance their assimilation (Wills,

Table 3
The proportion of particular fruit supplying polyphenols to the human organism in dependence of selected factors according to AHP method

Fruit	Dry mass content	Polyphenol content	The amount of consumption	Vitamin C content	Saccharides content	Sum
Apples	0.0226	0.0127	0.201	0.0047	0.0037	0.2447
Orange	0.0309	0.0201	0.0788	0.0173	0.0024	0.1495
European elder	0.0484	0.0801	0.0053	0.0108	0.0012	0.1458
Grapefruit	0.0055	0.0421	0.0571	0.0116	0.0017	0.118
Kiwi	0.0127	0.0266	0.0285	0.0238	0.0069	0.0985
White grapes	0.0086	0.0081	0.0444	0.0033	0.0096	0.074
Plum	0.0122	0.0174	0.0352	0.0026	0.0035	0.0709
Pink grapes	0.0193	0.008	0.0213	0.0033	0.0096	0.0615
Nectarine	0.0049	0.0051	0.0156	0.0069	0.0046	0.0371

Table 4
The proportion of particular vegetables supplying polyphenols to the human organism in dependence of selected factors according to AHP method

Vegetables	Dry mass content	Polyphenol content	The amount of consumption	Vitamin C content	Sugars content	Sum
Italian cabbage	0.0107	0.0264	0.1152	0.0118	0.0071	0.1712
Carrot	0.0134	0.0377	0.0988	0.0019	0.0071	0.1589
Broccoli	0.0223	0.0641	0.0216	0.0143	0.0027	0.125
Tomato	0.0076	0.0154	0.0846	0.0054	0.0022	0.1152
Parsley root	0.0439	0.018	0.0322	0.0078	0.0097	0.1116
Brussels sprouts	0.0298	0.0227	0.0251	0.0167	0.0035	0.0978
Onion	0.0156	0.0323	0.0376	0.0028	0.0071	0.0954
Celery root	0.0191	0.0132	0.0438	0.0035	0.0027	0.0823
Zucchini	0.0089	0.0092	0.0185	0.004	0.0019	0.0425

2000). Saccharides (mainly monosaccharides) bound to polyphenols act as hydrogen ligands in hydroxyl groups of these compounds. In fruit, saccharides constitute between 5% and 15%, whereas their concentrations in vegetables fluctuate more (Jarczyk & Berdowski, 1999).

All these factors were considered while developing models of polyphenol supply from fruit and vegetables to the human organism. The results of total polyphenol and dry mass contents in fruit and vegetables, the data on the analysed raw material consumption in Poland (Cieślik, Florkiewicz, & Filipiak–Florkiewicz, 2001; Halicka & Kowrygo, 2002; Michota–Katulska, 2002), as well as content of vitamin C and total saccharides (Kunachowicz, Nadolna, & Iwanow, 2001) were used to develop the above-mentioned model.

Models for improving the state of human health by supplying polyphenols from fruit or vegetables were developed according to the following schedule.

1. Formulating a problem – learning the factors affecting polyphenol supply to the human organism and enhancing their positive effect.
2. Identifying the overall goal – improvement of human health through polyphenol supply from fruit or vegetables.
3. Presentation of the problem structure as a hierarchical model (Figs. 1 and 2) – determining criteria (objectives) and sub-criteria (sub-objectives) influencing the overall goal and variants presenting form of consumption of analysed plant raw materials.
4. Establishing the dominance (preference) of the main criteria by pair-wise comparisons of their importance for realization of the overall goal.
5. Establishing the dominance of sub-criteria (sub-objectives) by pair-wise comparisons of their importance for realization of the overall goal.
6. Elaborating decision variants satisfying sub-criteria (sub-objectives) and criteria of the overall goal.
7. Establishing dominance of the elaborated variants by pair-wise comparisons of their importance for realization of each sub-criterion (sub-objective) in turn.
8. Presentation of verbal judgements by means of significant numbers on the Saaty's fundamental scale of preference.
9. Utilisation of these numbers for calculating priority of elements in the hierarchy in relation to their influence upon the overall goal.
10. Synthesis of the obtained results necessary for determining the best fruit (or vegetable) and the variant, i.e., the form of its consumption, which would contribute most to polyphenol supply to the human organism.

Fig. 1 presents the hierarchy of polyphenol supply from fruit, which affects an improvement of consumer health according to AHP. The following have been classified as the general criteria (level II of the hierarchy): contents of dry mass, polyphenols, vitamin C, saccharides and the amount of fruit and vegetable consumption in Poland. While developing hierarchical structure on level III, the following sub-criteria (sub-objectives) were assumed in relation to the main criteria: apple, orange, European elder, grapefruit, kiwi fruit, green grapes, plum, pink grapes and nectarine. Level IV of this structure comprised four variants of the analysed fruit consumption: A – raw, B – juice, C – as chilled fruit and D – preserves.

Fig. 2 shows the hierarchy of vegetable polyphenol supply influencing the improvement of consumer health. While building this structure on Level II, the analogous main criteria were assumed, as for the hierarchy of fruit polyphenol supply. In this case, the sub-criteria (sub-objectives) on level III comprised vegetables, namely Italian cabbage, carrots, broccoli, tomato, parsley root, Brussels sprouts, onion, celery, and zucchini. Moreover, decision variants A, B, C and D, the same as in the first hierarchy, were presented on level IV of this hierarchy.

On each hierarchical level, elements were compared pair-wise. The comparisons considered which of the elements was more important for realization of an individual criterion (objective) or the overall goal. The judgements were shown in Saaty's preference scale within the 1–9 range, i.e., from equal to extreme.

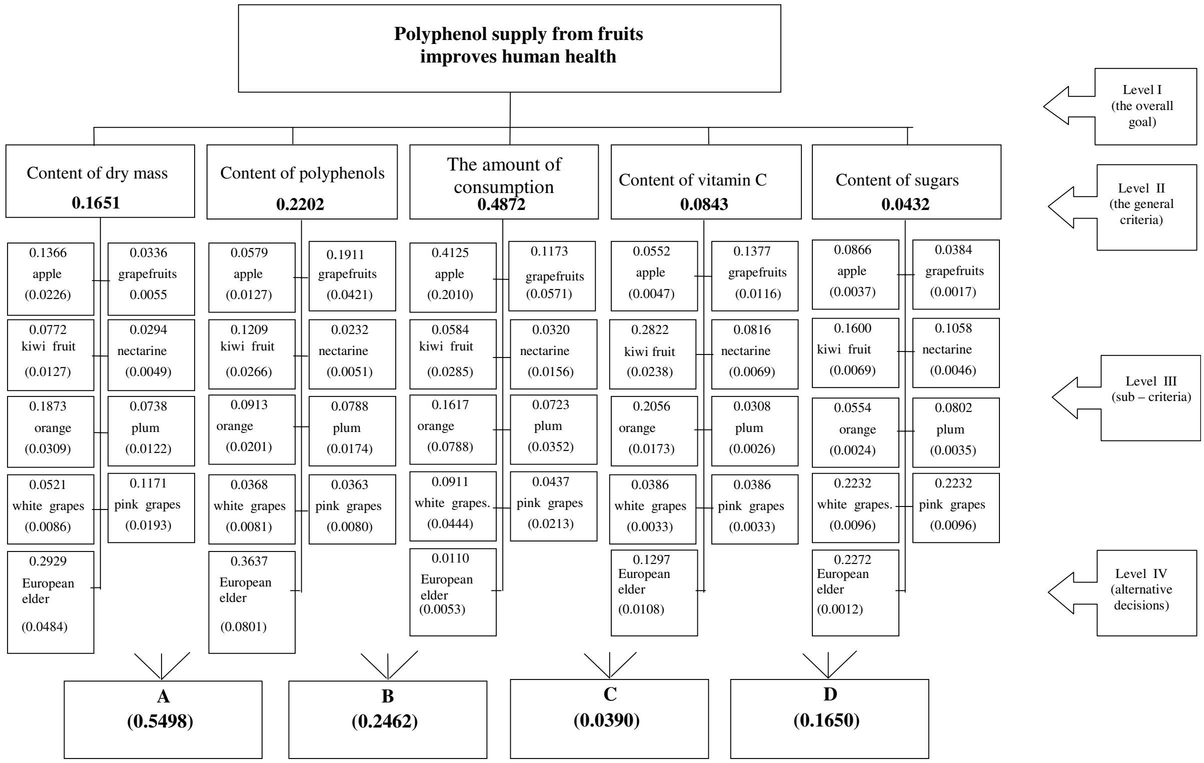

Fig. 1. Polyphenol supply from fruits improves human health. Source: Own elaboration.

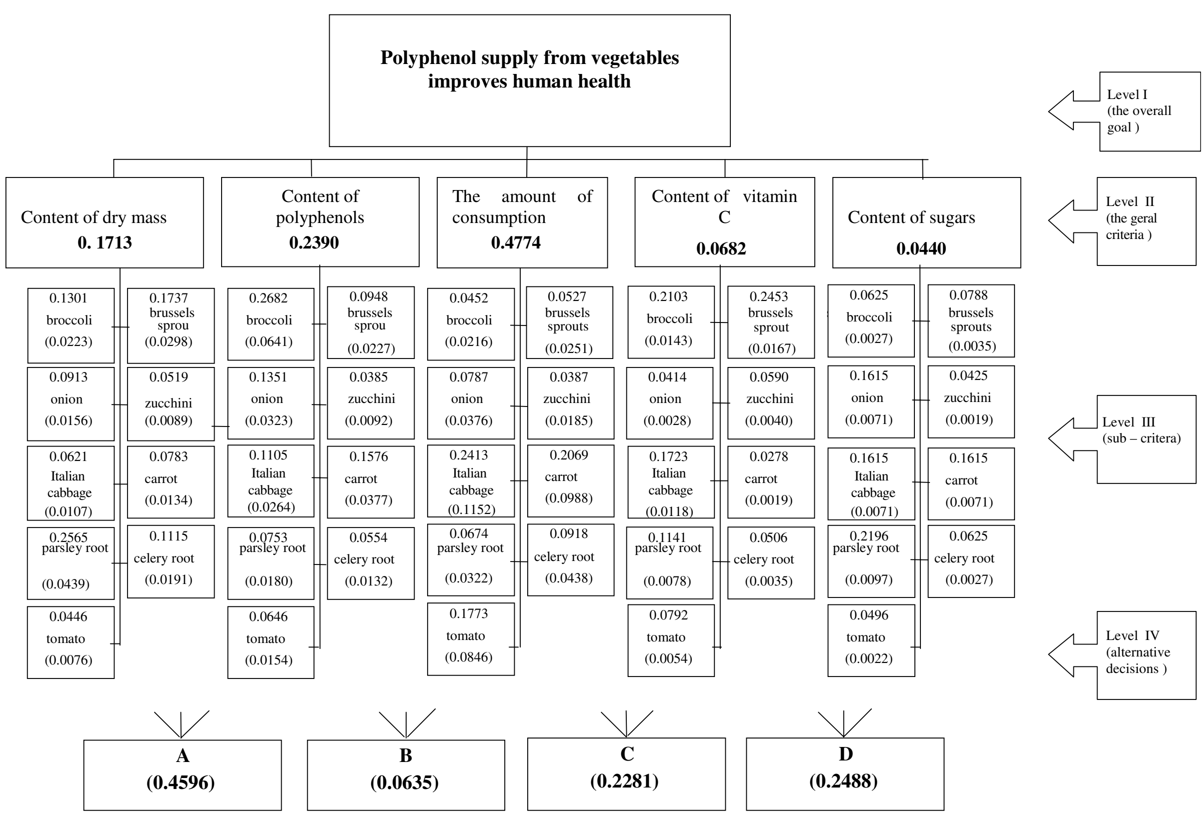

Fig. 2. Polyphenol supply from vegetables improves human health. Source: Own elaboration.

Subsequently, the priorities of each element in relation to the overall goal were calculated by means of square comparison matrix. This was done according to Saaty's recommendations (1990), which state that the maximum size of the comparison matrix should not exceed 10 elements. In the developed models the comparisons did not exceed nine elements ($n = 5$ on level II, $n = 9$ on level III and $n = 4$ on level IV). A total of 1840 comparisons were made in 102 matrices.

The values given, both in Tables 3 and 4 and in Figs. 1 and 2, denote priorities of individual elements in the realisation of the overall goal, i.e., improvement of consumer health. The values in brackets, shown in figures, are results of priority multiplication on levels II and III. A model value 0.0226 for apples given in brackets in Fig. 1 is a result of multiplication of 0.1366 (priority for apples, resulting from comparison matrix of the elements on level III, with reference to an element situated on level II – dry mass content) and priority for dry mass content 0.1651. A grand total of values given in brackets, equals the element priority to which we refer the comparisons (0.1651). On the other hand, the total sum of all priorities on each level equals one.

Priorities for each of the analysed fruits shown in Table 1 and for vegetables given in Table 2, obtained on the basis of pair-wise comparisons of the elements with reference to each of the assumed criteria for realization of the main aim, were summed. This was done to provide a basis for arranging, according to the weight of the priorities, both individual fruits and vegetables, in groups, indicating which most and the least contribute to polyphenol supply to the organism and positively affect the state of human health.

The obtained results have demonstrated that apples are the fruit, having the greatest influence on realization of the overall objective. The priority it has gained is 0.2447. This allows for a conclusion that this raw material, almost in 25%, affects polyphenol supply to our organism. The result was obtained in the analysed model through a complex approach to the problem, not only considering the consumption of this raw material in Poland. As may be seen, the factor significantly affected the final result because prevail in the structure of fruit consumed in Poland. They constitute about 50% of fresh fruit consumed by households.

On the other hand, the fruit with the lowest priority 0.0371, was the nectarine. Thus it may be concluded that it will contribute least to polyphenol supply to the human organism. Among vegetables, cabbage got the highest priority (0.1712) and zucchini the lowest (0.0425).

Both apples and cabbage which, as demonstrated by conducted comparisons, achieved the highest priorities, are raw materials very popular among consumers in Poland. Their popularity may be due to the region of their cultivation, to traditional consumption habits, to raw material availability on the market all the year round, and also their low price.

An increased consumption of exotic fruit, reaching 20% of the total fruit consumption, has recently been observed in Poland, which shows that they are gaining in importance in polyphenol supply to our organism and are a factor for improvement of health. Moreover, level IV (Fig. 2) shows global priorities for the overall goal realisation for the four variants of the analysed fruit consumption: A, B, C and D. They were computed by pair-wise comparison of the assumed forms of consumption, which were referred to each sub-criterion n(sub-objective) first in the hierarchy of polyphenol supply from fruit and then from vegetables. The results of calculations for fruits are presented in Table 5. A global priority function, U, was developed, using the following formula:

$$U = 0.5498\ U_A + 0.2462\ U_B + 0.0390\ U_C + 0.1650\ U_D.$$

This demonstrates that fruit eaten fresh have the greatest effect on improvement of human health through supply of polyphenols. Variant A gained the highest priority 0.5498, so it most fulfils criteria (objectives) for and sub-criteria (sub-objectives) of AHP.

The analogous calculations made for vegetables yielded results gathered in Table 6. A global priority function, developed on this basis, was expressed by the following formula:

$$U = 0.4596\ U_A + 0.0635\ U_B + 0.2281\ U_C + 0.2488\ U_D.$$

It may be concluded that form A, which gained the highest priority (0.4596), is the best variant of vegetable consumption, best contributing to realisation of the assumed overall objective, whereas variant B, i.e., juices, proved the least effective form of polyphenol supply from vegetables as it gained the lowest priority 0.0635.

Summing up it may be said that the results obtained by comparing individual variants among themselves, with reference to all criteria and sub-criteria of the considered hierarchical models at the same time, confirm the fruit and vegetable consumption forms most popular in Poland. This results from the fact that both raw materials are most frequently consumed fresh, whereas chilled fruit and vegetable juices are less popular. On this basis, it may be said that these forms of consumption, to the greatest or smallest degree, will contribute to polyphenol supply to the organism and maintaining good health.

In order to check whether no error was made in pairwise comparisons, the consistency ratio (CR) was calculated, which is a measure of consequence in judgements.

Table 5
The comparison of the AHP results for fruit – relative proportion of each sub-criterion in particular models in realisation of overall objective

Fruit	Variant of fruit consumption			
	Raw	Juice	Chilled fruit	Preserves
Dry mass content				
Apples	0.0083	0.0033	0.0007	0.0103
Grapefruit	0.003	0.0014	0.0002	0.0009
Kiwi	0.0067	0.0015	0.0004	0.0041
Nectarine	0.0026	0.0006	0.0016	0.0001
Orange	0.0166	0.008	0.001	0.0053
Plum	0.003	0.0004	0.0022	0.0068
White grapes	0.0044	0.0014	0.0003	0.0025
Pink grapes	0.01	0.0031	0.0006	0.0056
European elder	0.016	0.0103	0.0016	0.0205
Polyphenols content				
Apples	0.007	0.004	0.0004	0.0016
Grapefruit	0.0236	0.0136	0.0012	0.0038
Kiwi	0.0172	0.0065	0.0007	0.0022
Nectarine	0.0033	0.0012	0.0001	0.0004
Orange	0.0112	0.0064	0.0006	0.0019
Plum	0.0096	0.0005	0.0048	0.0025
White grapes	0.0053	0.0018	0.0002	0.0008
Pink grapes	0.0053	0.0018	0.0002	0.0008
European elder	0.0378	0.0242	0.0027	0.0154
The amount of consumption				
Apples	0.1237	0.0535	0.0065	0.0173
Grapefruit	0.034	0.0196	0.0017	0.0018
Kiwi	0.0197	0.0038	0.0009	0.0041
Nectarine	0.0073	0.0051	0.0005	0.0027
Orange	0.0461	0.023	0.0022	0.0075
Plum	0.0201	0.0011	0.0014	0.0126
White grapes	0.0263	0.0111	0.0013	0.0057
Pink grapes	0.0133	0.0048	0.0006	0.0025
European elder	0.0002	0.0036	0.0002	0.0012
Vitamin C content				
Apples	0.0026	0.0013	0.0001	0.0007
Grapefruit	0.0068	0.0034	0.0003	0.0011
Kiwi	0.0154	0.0058	0.0006	0.0002
Nectarine	0.0042	0.0017	0.0002	0.0007
Orange	0.0097	0.0056	0.0005	0.0015
Plum	0.0016	0.0001	0.0001	0.0007
White grapes	0.002	0.0008	0.0001	0.0003
Pink grapes	0.002	0.0008	0.0001	0.0003
European elder	0.0051	0.0033	0.0004	0.0021
Sugars content				
Apples	0.0013	0.0007	0.0001	0.0016
Grapefruit	0.0008	0.0005	0.0001	0.0003
Kiwi	0.0033	0.0013	0.0002	0.0021
Nectarine	0.0022	0.0009	0.0002	0.0014
Orange	0.0011	0.0005	0.0001	0.0007
Plum	0.0007	0.0001	0.0005	0.0022
White grapes	0.0045	0.0018	0.0003	0.0029
Pink grapes	0.0045	0.0018	0.0003	0.0029
European elder	0.0004	0.0002	0.00004	0.0006
Sum	0.5498	0.2462	0.0390	0.1650

Table 6
The comparison of the AHP results for vegetables – relative part of each of sub-criterion in particular models in realisation of overall objective

Vegetables	Variant of fruit consumption			
	Raw	Juice	Chilled vegetables	Preserves
Dry mass content				
Broccoli	0.0105	0.0007	0.0043	0.0067
Brussels sprouts	0.0141	0.001	0.0057	0.009
Onion	0.0074	0.0005	0.003	0.0047
Zucchini	0.0042	0.0003	0.0017	0.0027
Italian cabbage	0.0054	0.0003	0.0015	0.0034
Carrot	0.0065	0.0012	0.0021	0.0036
Parsley root	0.0207	0.0015	0.0084	0.0133
Celery root	0.009	0.0006	0.0037	0.0058
Tomato	0.0013	0.0004	0.0007	0.0051
Polyphenols content				
Broccoli	0.0352	0.002	0.0178	0.0091
Brussels sprouts	0.0125	0.0007	0.0063	0.0032
Onion	0.0177	0.001	0.009	0.0046
Zucchini	0.0047	0.0003	0.0029	0.0013
Italian cabbage	0.0125	0.0009	0.0051	0.008
Carrot	0.0168	0.0038	0.009	0.0081
Parsley root	0.01	0.0006	0.0046	0.0039
Celery root	0.0073	0.0004	0.0034	0.0021
Tomato	0.004	0.0022	0.0012	0.008
The amount of consumption				
Broccoli	0.0128	0.0006	0.0059	0.0023
Brussels sprouts	0.0021	0.0012	0.0158	0.006
Onion	0.0222	0.0013	0.0055	0.009
Zucchini	0.0058	0.0006	0.0094	0.0027
Italian cabbage	0.0585	0.0036	0.0167	0.0364
Carrot	0.0451	0.0171	0.0288	0.0077
Parsley root	0.0056	0.0014	0.0158	0.0095
Celery root	0.0210	0.0034	0.0118	0.0075
Tomato	0.0358	0.0098	0.0059	0.0331
Vitamin C content				
Broccoli	0.0083	0.0005	0.0028	0.0027
Brussels sprouts	0.0079	0.0006	0.005	0.0032
Onion	0.0016	0.0001	0.0001	0.0005
Zucchini	0.0019	0.0001	0.0012	0.0008
Italian cabbage	0.0032	0.0005	0.0015	0.0066
Carrot	0.0009	0.0005	0.0003	0.0002
Parsley root	0.0043	0.0003	0.0022	0.0011
Celery root	0.0019	0.0001	0.001	0.0005
Tomato	0.0026	0.0015	0.0004	0.0010
Sugars content				
Broccoli	0.0013	0.0001	0.0005	0.0008
Brussels sprouts	0.0017	0.0001	0.0007	0.0011
Onion	0.0021	0.0002	0.0012	0.0035
Zucchini	0.0009	0.0001	0.0004	0.0006
Italian cabbage	0.0036	0.0002	0.001	0.0022
Carrot	0.0018	0.0006	0.001	0.0037
Parsley root	0.0046	0.0003	0.0019	0.0030
Celery root	0.0013	0.0001	0.0005	0.0008
Tomato	0.001	0.0002	0.0004	0.0006
Sum	0.4596	0.0635	0.2281	0.2488

This was done on the basis of maximum eigen value from the comparison matrix. The value of CR in the analysed sample ranged between 2.0% and 10.6% (mean 5.14) for fruit and between 0 and 4.79 (mean 2.83) for vegetables, which means that the comparisons were consistent.

4. Conclusions

1. Raw materials providing an important source of polyphenols in Poland include apples (among fruit) and cabbage (among vegetables). They gained the highest ranks in results of comparison conducted using the AHP method, which for apples gave 0.2447 and for cabbage 0.1712.
2. The larger proportion of fresh fruit and vegetables in the consumed diets is most important as their consumption contributes to the greatest supply of polyphenols.
3. The AHP method may be applied to solve multi-criteria problems in food and nutritional sciences.

References

Adamus, W., & Gręda, A. (2002). Wzbogacanie żywności w składniki biologicznie aktywne. *Żywienie Człowieka Metabolizm* (Suppl. 29), 421–429 (in Polish).

Adamus, W., & Zając, T. (2001). Określenie całkowitej użyteczności gryki przy pomocy analitycznego procesu hierarchicznego. *Sesja Naukowa. Zeszyty Naukowe AR w Krakowie, 392*(85), 53–66 (in Polish).

AOAC. (1995). In Herlich K. (Ed.), *Official methods of analysis the assiociation of official analytical chemists* (15th ed).

Bengoechea, M. L., Sancho, A. I., Bartolome, B., et al. (1997). Phenolic composition of industrially manufactured purees and concentrates from peach and apple fruits. *Journal of Agriculture and Food Chemistry, 45*, 4071–4075.

Borowska, J., Zadernowski, R., & Waźbińska, J., et al. (2000). Charakterystyka chemiczna owoców bzu czarnego (Sambus nigra L.), [w:] III Ogólnopolskie Sympozjum: *Nowe rośliny i technologie w ogrodnictwie. Poznań, 25–26 września 2000. Sadownictwo. Roczniki AR w Poznaniu - Ogrodnictwo*, cz. 2, Poznań, 13–17 (in Polish).

Bravo, L. Ph. D. (1998). Polyphenols: chemistry, dietary sources, metabolism, and nutritional significance. *Nutrition Reviews, 11*, 317–333.

Buren, J., Vos, L., & Pilnik, W. (1976). Polyphenols in golden delicious apple juice in relation to method of preparation. *Journal of Agriculture and Food Chemistry, 3*, 448–451.

Cieślik, E., Florkiewicz, A., & Filipiak–Florkiewicz, A. (2001). Spożycie warzyw i owoców w Polsce w latach1989–1998. *Zywienie Człowieka Metabolizm*(Suppl. 28) (in Polish).

Darlington, L. G., & Stone, T. W. (2001). Antioxidants and fatty acids in the amelioration of rheumatoid arthiritis and related disorders. *British Journal of Nutrition, 85*, 251–269.

Fogliano, V., Verde, V., Randazzo, G., et al. (1999). Method for measuring antioxidant activity and its application to monitoring the antioxidant capacity of wines. *Journal of Agriculture and Food Chemistry, 47*, 1035–1040.

Halicka, E., & Kowrygo, B. (2002). Ocena zmian w spożyciu owoców w Polsce. *Przemtsł Spożywczy, 10*, 26–28 (in Polish).

Heinonen, I. M., Lehtonen, P. J., & Hopia, A. I. (1998). Antioxidant activity of berry and fruit wines and liquors. *Journal of Agriculture and Food Chemistry, 46*, 25–31.

Hojden, B. (2000). Herbata zielona i jej właściwości lecznicze. *Wiadomości Zielarskie, 9*, 14–15 (in Polish).

Horbowicz, M. (2000). Występowanie, biosynteza i właściwości biologiczne flawonoli. *Postępy nauk rolniczych, 2*, 3–18 (in Polish).

Hurtado, I., Caldu, P., Gonzalo, A., et al. (1997). Antioxidative capacity of wine on human LDL oxidation in vitro: effect of skin contact in winemaking of white wine. *Journal of Agriculture and Food Chemistry, 45*, 1283–1289.

Jarczyk, A. & Berdowski, J. B. (1999). *Przetwórstwo owoców i warzyw*, cz.1, WSP, Warszawa (in Polish).

Kunachowicz, H., Nadolna, I., & Iwanow, K. (2001). Wartość odżywcza wybranych produktów spożywczych i typowych potraw. Wyd. Lekarskie PZWL. Warszawa (in Polish).

Lu, Y., & Foo, Y. (1997). Identification and qualification of major polyphenols in apple pomace. *Food Chemistry, 2*, 187–194.

Michota–Katulska, E. (2002). Zróżnicowanie regionalne konsumpcji wybranych produktów żywnościowych w gospodarstwach domowych rolników i pracowników. *Handel wewnętrzny, 10*, 139–144 (in Polish).

Nijveldt, R. (2000). Flavonoids: a review of probable mechanisms of action and potential applications. *American Journal of Clinical Nutrition, 74*, 418–425.

Oleszek, W., Lee, C. Y., Jaworski, A. W., et al. (1988). Identification of some phenolic compounds in apples. *Journal of Agriculture and Food Chemistry, 36*, 430–432.

Pelegrinin, N., Simonetti, P., Gordana, C., et al. (2000). Polyphenol content and total antioxidant activity of Vini Novelli (Young red wines). *Journal of Agriculture and Food Chemistry, 48*, 732–735.

Perucka, I. (2001). Skład chemiczny liści herbaty. *Biul. Magnezol. 6*(3), 443–451 (in Polish).

Saaty, T. L. (1990). *The analytic hierarchy process*. New York: McGraw-Hill.

Shahidi, F., Janitha, P. K., & Wanasundara, P. D. (1992). Phenolic antioxidanta. *Critical Reviews in Food Science and Nutrition, 32*(1), 67–103.

Shrikhande, A. J., & Franch, F. J. (1974). Effect of flavonols on ascorbic acid and anthocyanin stability in model systems. *Journal of Food Science, 39*, 904–906.

Soleas, G. J., Dam, J., Carey, M., et al. (1997). Toward the fingerprinting of wines: cultivar-related patterns of polyphenolic constituents in ontario wines. *Journal of Agriculture and Food Chemistry, 45*, 3871–3880.

Ślężko, D. (1996). *Ćwiczenia z biochemii*. Wyd. AR. Szczecin (in Polish).

Świderski, F. (red.). (2000). *Żywność wygodna izywność funkcjonalna*. WNT. Warszawa (in Polish).

Szczypka, M. (1997). Wolne rodniki i obrona antyoksydacyjna. *Przemysł Spożywczy, 4*, 16–18 (in Polish).

Vinson, J. A., & Hontz, B. A. (1995). Phenol antioxidant index: comparative antioxidant effectiveness of red and white wines. *Journal of Agriculture and Food Chemistry, 43*, 401–403.

Wills, J. (2000). *Biblia żywności i żywienia*. Wyd., "Amber" (in Polish).

Zduńczyk, Z. (1999). Znaczenie biologicznie aktywnych nieodzywczych składników diet w zapobieganiu chorobom cywilizacyjnym. *Żywność, 4*(Suppl. 21), 75–89 (in Polish).