Exposure of the population of the Slovak Republic to nitrates

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Summary
In the paper, the exposure of the population of the Slovak Republic to nitrates has been estimated. On the results of 223 798 analysis of food, raw materials of plant and animal origin, beverages and water contained in the database of the Centre for Evaluation of Food Contaminants Occurence for the period of 1990 to 2003. The exposure upon the average person was estimated by using figures of actual consumption of foods and beverages, and it was compared with the acceptable daily intake (ADI) value set for the nitrate anion. Contributions of different categories of foods and beverages to the nitrate exposure were calculated. The estimated exposure was lower throughout the reference period than the set ADI values.

Keywords
nitrates; intake; exposure; foods; water; ADI

Nitrates are either food additives or contaminants which, at low concentrations, occur also naturally in the environment, and they represent an inseparable constituent of nitrogen turnover in the nature [1].

Nitrogen present in the soil gets converted by the action of microorganisms into atmospheric nitrogen; most of it is taken by plants, and but small percentages of it get to the ground waters in the form of nitrates [2].

Foods of plant origin represent another important source of nitrates. Their concentrations in plant materials are above all dependent on the extent of the use of industrial fertilizers as well as upon pedological and climatic conditions [3, 4].

Taken in through feeds and water, nitrates become part of biochemical reactions in also the animal body. Enhanced nitrogen exposure of the animal body over long periods of time may negatively impact upon animal health condition as well as upon the quality of foods of animal origin. Elevated nitrate concentrations in those commodities may also result from their use during the production process aiming at colour stabilisation upon preserving meat products, protecting them from microbial contamination, enhancing the typical flavour and taste, protection of lipids against oxidation and subsequent extension of the shelf life of meat products.

At low concentrations and in non-reducing environments, nitrates are not dangerous to healthy adults as they get relatively rapidly reduced in the kidneys. Their potential toxicity in foods is due to potential reduction to a lower degree of oxidation – nitrites, which may cause health problems both in children and adults. Nitrates get reduced both endogenously and exogenously. Exogenous reduction occurs mainly during transport, storage and processing of agricultural products. Exogenous reduction occurs in the oral cavity [5].

In the proximal small intestine, nitrates are rapidly and almost completely absorbed (bioavailability at least 92%) into blood and tissues. In humans approximately 25% of the nitrate ingested is secreted in saliva, where some 20% (about 5–8% of the nitrate intake) is converted to nitrite by commensal bacteria. The nitrite so formed is then absorbed primarily in the small intestine [6]. Most of the nitrates are excreted by the kidneys (in young people around 80% and in older people about 50%) after 4 or 12 hours. The remainder remains in the body. In the blood, nitrates get to salivary glands to concentrate there and to return to the oral cavity [5].

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Nitrates are primarily weakly toxic substances; they however are precursors of nitrites which may cause methaemoglobinaemia by inactivating haemoglobin in the body, in particular in children during their early months of life [7]. However, recent studies have demonstrated that nitrites, upon their ingestion and mixture with gastric acid, are also potent bacteriostatic and/or bactericidal agents and may be an element of innate immunity [8]. Epidemiological studies have also shown that dietary nitrates may have an important therapeutic role to play. Nitrates are emerging as effective host defence against gastrointestinal pathogens, as modulators of platelet activity and possibly even of gastrointestinal mobility and microcirculation [9].

The biggest nitrates-related hazard however is represented by the potential formation of N nitrous compounds able to induce the development of tumours in all body organs, except bone. They are formed through nitrite reactions with secondary as well as tertiary amines. To become nitrated, amines must be in excess. Dried salted fish (smoked or grilled) and baked salami are of special hazard, as nitrosamines are directly present in them. Antioxidants, such as vitamin C in water environment and vitamin E in fats prevent the formation of these compounds [10]. Reduction of nitrate contents in the food can prevent the development of cancer disease [4].

The issues of the negative impact of nitrates on human health are subject of the general public interest. Exposure may reach levels which are associated with enhanced probability of negative health effects. The high-risk commodities mainly include raw materials and foods of plant origin into which nitrates get from the environment, and – to a lesser extent – foods of animal origin, to which nitrates are added to improve their technological and organoleptic properties. Also, vegetarians may be exposed to a higher risk of burden as they consume more plant products which may be the source of markedly enhanced exposure to nitrates.

The consequences of the presence in the food of nitrates require tight control of nitrate concentrations in agricultural raw materials and food products. In the Slovak Republic, it is control and diagnostic institutions of Ministry of Agriculture of the Slovak Republic (State Veterinary and Food Authority of the Slovak Republic), Research Institute of Water Management, Water and Sewer Authority, Hydromeliorácie š. p., all of which are in charge of the controls and analyses of samples. The results of the analyses are then provided by the organisations mentioned to Centre for Evaluation of Food Contaminants Occurence established at the Food Research Institute in Bratislava.

The aim of this study has been to evaluate the dietary exposure of the Slovakian population to nitrates and to compare the total daily intake into the human organism with the corresponding ADI values.

MATERIALS AND METHODS

Dietary exposure of the population to nitrates observed in 1990 was compared with that found in 2003. The foods analysed were classified in 21 groups of food commodities (Tab. 1). This was based on 2002 data provided by the Statistical Office of the Slovak Republic on the consumption of food, beverages and water. They concerned consumption of basic groups of foods calculated by the HBS (Household Budget Survey) method [11].

Estimates of nitrate intake were based on the database of results of analyses of 223 798 samples of basic food raw materials, beverages and water kept at the Centre for Evaluation of Food Contaminants Occurence taken in the Slovak Republic since 1986 at agricultural holdings, food industry enterprises, retail network as well as households. The exposure calculations used average, median values and 95th percentile values of nitrate concentrations in the different groups

Tab. 1. Statistical data on the consumption of selected types of food commodities.

Commodity	Consumption [g per person per day]
meat	42.81
poultry and poultry meat products	45.58
meat preserves	4.57
meat products	40.94
fish and fish products	10.47
cheese	12.29
diary products	46.97
fats and oils	43.95
vegetable products	4.43
leafstalk vegetables	19.23
fruit vegetables	43.31
leaf vegetables	2.75
root vegetables	15.42
potatoes	96.00
legumes	0.45
fruit products	2.50
kernel fruits	43.34
citrus fruits	23.67
other foods	102.74
beverages	327.38
water	2000.00

of foods, beverages and water. To provide for data comparable to nitrate intake levels in other countries, the body weight of an average adult in the Slovak Republic was taken to be 70 kg.

The calculated nitrate exposure levels were compared with the acceptable daily intake values (hereinafter ADI). The ADI values set by the independent Joint FAO/WHO Expert Committee on Food Additives and Contaminants (JECFA) set the following ADI values for nitrate anion and $NaNO_3$: 3.7 mg per kg body weight per day [10, 12] and 5.0 mg per kg body weight per day [13], respectively. For agricultural commodities for which the nitrate limits are expressed in terms of $NaNO_3$, the results were converted to NO_3^- values (using the conversion coefficient of 0.73).

RESULTS AND DISCUSSION

Nitrate intakes were estimated based on statistical data on the consumption of selected types of food commodities (see Table 1). Commodities were included in the evaluation in respect of which data on average and median nitrate concentrations obtained for the different years during the period of observation were representative and were sufficiently valid.

Table 2 shows nitrate intakes in 1990 calculated based on actual consumption, using average, median values and the value of the 95th percentile, along with their shares on the acceptable daily intake. In 1990, nitrate intake reached as many as 156.5% ADI (in terms of the 95th percentile), 57.1% ADI (in terms of average values), and 40.01% ADI (in terms of median nitrate concentrations) in the different commodities studied.

Taking the average concentrations as the basis, water accounted for the highest intake of NO_3^- in 1990 (0.76 $mg.kg^{-1}$ body weight per day), in particular because of the high actual water consumption. Beverages and potatoes accounted for less intake (0.41 $mg.kg^{-1}$ body weight per day and 0.24 $mg.kg^{-1}$ body weight per day, respectively).

Similar levels of nitrate intake were obtained based on calculations accounting for median concentrations. Smaller values were only obtained for water, through which 0.39 mg nitrates per kg body weight was getting into the body of an average adult per day.

Taking the 95th percentile as the basis, nitrate intake in water was estimated at almost 2.6 $mg.kg^{-1}$ body weight per day, representing as much as almost 70% of acceptable daily intake. Accounting for the 95th percentile, nitrate intake through other commodities ranged between

Tab. 2. Assessment of nitrate exposure from selected food commodities in 1990.

Commodity	Intake [mg per kg body weight per day]			% ADI	
	average concentration	median	95th percentile	median	95th percentile
meat	0.0004	0.0004	0.0004	0.01	0.01
poultry and poultry meat products	0.0138	0.0070	0.0441	0.19	1.19
meat preserves	0.0020	0.0003	0.0110	0.01	0.30
meat products	0.0343	0.0222	0.0847	0.60	2.29
fish and fish products	0.0025	0.0009	0.0082	0.02	0.22
cheese	0.0001	0.0001	0.0001	0.003	0.003
diary products	0.0005	0.0005	0.0005	0.01	0.01
fats and oils	0.0334	0.0318	0.0779	0.86	2.11
vegetable products	0.0090	0.0063	0.0256	0.17	0.69
leafstalk vegetables	0.1679	0.1467	0.4003	3.96	10.82
fruit vegetables	0.1158	0.0742	0.3802	2.01	10.28
leaf vegetables	0.0225	0.0137	0.0763	0.37	2.06
root vegetables	0.0970	0.0780	0.2519	2.11	6.81
potatoes	0.2445	0.2167	0.5916	5.86	15.99
legumes	0.0007	0.0003	0.0020	0.01	0.05
fruit products	0.0054	0.0014	0.0178	0.04	0.48
kernel fruits	0.0067	0.0062	0.0142	0.17	0.38
citrus fruits	0.0247	0.0225	0.0439	0.61	1.19
other foods	0.1595	0.0603	0.5552	1.63	15.00
beverages	0.4107	0.4022	0.6594	10.87	17.82
water	0.7618	0.3886	2.5450	10.50	68.78
Total	2.1133	1.4805	5.7906	40.01	156.50

Tab. 3. Assessment of nitrate exposure from selected food commodities in 2003.

Commodity	Intake [mg per kg body weight per day]			% ADI	
	average concentration	median	95th percentile	median	95th percentile
meat	0.0089	0.0084	0.0171	0.23	0.46
poultry and poultry meat products	0.0102	0.0092	0.0225	0.25	0.61
meat preserves	0.0012	0.0010	0.0031	0.03	0.08
meat products	0.0127	0.0103	0.0327	0.28	0.88
fish and fish products	0.0019	0.0019	0.0025	0.05	0.07
cheese	0.0009	0.0001	0.0041	0.003	0.11
diary products	0.0040	0.0005	0.0168	0.01	0.46
fats and oils	0.0071	0.0052	0.0232	0.14	0.63
vegetable products	0.0295	0.0150	0.1127	0.40	3.05
leafstalk vegetables	0.1506	0.0876	0.4202	2.37	11.36
fruit vegetables	0.0829	0.0208	0.3505	0.56	9.47
leaf vegetables	0.0467	0.0387	0.1436	1.05	3.88
root vegetables	0.1447	0.0551	0.6227	1.49	16.83
potatoes	0.1972	0.1701	0.4224	4.60	11.42
legumes	0.0001	0.0001	0.0001	0.002	0.002
fruit products	0.0010	0.0007	0.0019	0.02	0.05
kernel fruits	0.0020	0.0009	0.0040	0.03	0.11
citrus fruits	0.0030	0.0017	0.0076	0.05	0.21
other foods	0.2263	0.0387	0.6627	1.05	17.91
beverages	0.3607	0.0129	1.3151	0.35	35.54
water	0.2471	0.1580	0.7771	4.27	21.00
Total	1.5387	0.6368	4.96262	17.21	134.12

0.0001 $mg.kg^{-1}$ and 0.66 $mg.kg^{-1}$ body weight per day, i.e. between 0.004% and 17.82% ADI.

Based on average, median and 95th percentile values, cheese and meat accounted for the least exposure to nitrates: 0.0001 $mg.kg^{-1}$ body weight per day and 0.0004 $mg.kg^{-1}$ body weight per day, respectively.

Fig. 1 illustrates what proportions of the daily acceptable intake were geting to the body through selected types of foods and beverages 1990, calculated based on average concentrations. Water contributed most pronouncedly to the intake (20.6% ADI). Beverages and potatoes contributed less (11.1% and 6.6% ADI, respectively), with cheese closing the group of the agricultural commodities with the lowest contribution of 0.004% ADI.

Table 3 showing nitrate intake in 2003 calculated based on average and median values and the 95th percentile and the shares on ADI suggests a slight reduction of the exposure compared with 1990. Beverages accounted for the major share of nitrate intake (in terms of average concentrations) - as much as 0.36 $mg.kg^{-1}$ body weight per day, due to high consumption (328 g per person per day in 2003). The doses of nitrates taken through water, other foods (spices, seasonings etc.) and potatoes were at approximately the level of 0.20 $mg.kg^{-1}$ body weight per day.

Using median values of concentrations, it was potatoes that accounted for the highest nitrate intakes of almost 0.17 $mg.kg^{-1}$ body weight per day (4.6% ADI). Water, leafstalk vegetables, root vegetables, leaf vegetables, and other foods contributed more than 1% of nitrate ADI (4.27%; 2.37%; 1.49%; 1.05%; and 1.05%, respectively).

Taking the 95th percentile as the basis, the highest nitrate intakes in 2003 were through beverages (35.54% ADI), representing 1.32 $mg.kg^{-1}$ body weight per day. Conversely, the least intakes were calculated for legumes: 0.001 $mg.kg^{-1}$ body weight, representing but 0.002% ADI.

Fig. 2 shows the proportions of the different commodities expressed in terms of the ADI value, as calculated based on average nitrate concentrations in 2003. It is evident that beverages accounted for the highest shares, making up approximately 9.8% ADI. Water and other foods accounted for intake at the 6.1–6.7% ADI level. The share of legumes, fruit products and cheese on total intake was less than 0.003% of acceptable daily intake. All these commodities except cheese belong to those with the lowest consumption pattern, causing consequently the lowest nitrate intake. Analytical findings in 2003 demonstrate fairly low nitrate contamination of cheese on the Slovak market, thus resulting in very low exposure of the population.

Comparing average nitrate concentrations in the different commodities, the commodities with the highest average concentrations however include leaf, root and leafstalk vegetables. Due to the low daily consumption however, this contributes relatively little to the overall exposure (between 1.3% ADI from leaf vegetables up to 4.1% ADI from leafstalk vegetables).

A similar situation was also observed in the Czech Republic in 2002; there, the commodi-

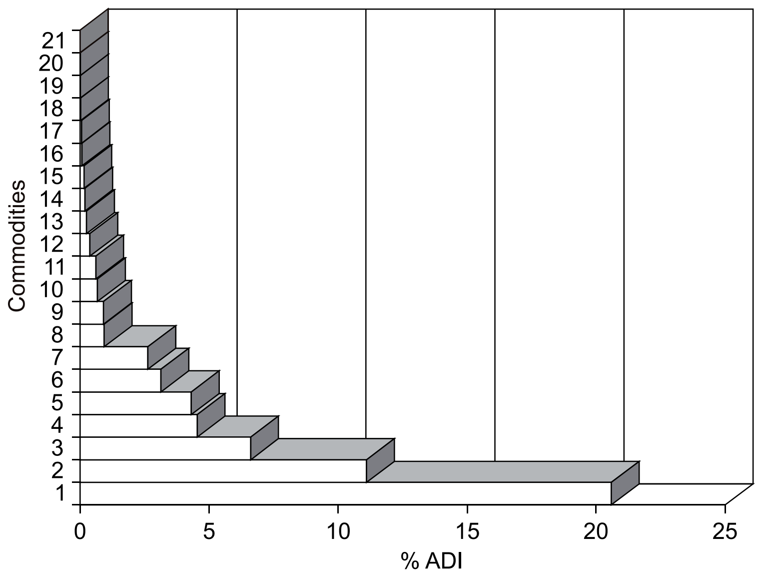

Fig. 1. Contributions by selected types of food commodities to ADI coverage in 1990 (average concentrations).

1 - water, 2 - beverages, 3 - potatoes, 4 - leafstalk vegetables, 5 - other foods, 6 - fruit vegetables, 7 - root vegetables, 8 - meat preserves, 9 - fats and oils, 10 - citrus fruits, 11 - leaf vegetables, 12 - poultry and poultry meat products, 13 - vegetable products, 14 - kernel fruits, 15 - fruit products, 16 - fish and fish products, 17 - meat products, 18 - legumes, 19 - diary products, 20 - meat, 21 - cheese, 22 - commodities.

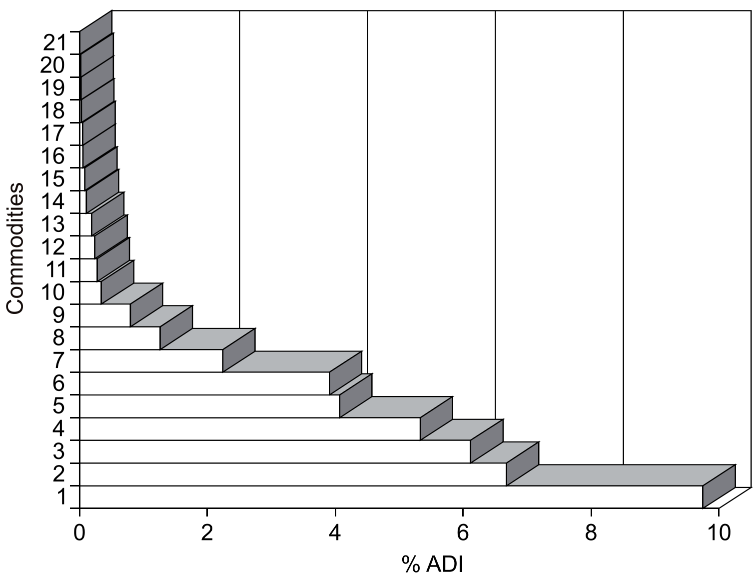

Fig. 2. Contributions by selected types of food commodities to ADI coverage in 2003 (average concentrations).

1 - beverages, 2 - water, 3 - other foods, 4 - potatoes, 5 - leafstalk vegetables, 6 - root vegetables, 7 - fruit vegetables, 8 - leaf vegetables, 9 - vegetable products, 10 - meat preserves, 11 - poultry and poultry meat products, 12 - meat, 13 - fats and oils, 14 - diary products, 15 - citrus fruits, 16 - kernel fruits, 17 - fish and fish products, 18 - meat products, 19 - fruit products, 20 - cheese, 21 - legumes, 22 - commodities.

Tab. 4. Comparison of nitrate intake and exposure in 1990 and 2003.

		Year	
		1990	2003
intake [mg per kg body weight per day]	average concentrations	2.11	1.54
	median concentrations	1.48	0.64
	95th percentile	5.79	4.96
% ADI	average concentrations	57.1	41.6
	median concentrations	40.0	17.2
	95th percentile	156.5	134.1

ties showing the highest nitrate concentrations included greenhouse and leaf vegetables, followed by root and leafstalk vegetables. Foods of animal origin represented but a limited source of nitrates also in the Czech Republic [14].

Summing up average nitrate concentrations in the different foods and beverages, the exposure per average person in 2003 reached 41.6% ADI; the respective figures for median concentrations and the 95th percentile values were 17.0% ADI and 134.1% ADI.

A different situation in respect of the nitrate exposure upon the population was observed in the Czech Republic in 2002. Using average concentrations of nitrates in foods and beverages, Total Diet Study (TDS) calculated intake at the 16% ADI level. The difference of the calculated nitrate intake between the Slovak Republic and the Czech Republic is due to the fact that TDS accounted for prepared meals (cooked, baked, etc.), due to which the nitrate concentrations get reduced [12]. Similarly, nitrates calculated under TDS in Denmark in 1997 accounted for 24% ADI and as little as 44% ADI when accounting for average concentrations and the 95th percentile, respectively [15].

TDS conducted in the UK showed similar values as calculated for the Slovak Republic (40–45% ADI based on average concentrations); however, taking the 95th percentile as the basis, the intake from foods and beverages was substantially smaller (60–75% ADI) [16].

Conversely, nitrate intakes higher than calculated for the Slovak Republic were noted for the Netherlands in 1997: 30% ADI using median concentrations [17].

Table 4 compares the average nitrate exposure calculated for 1990 and 2003. Similarly as in the Czech republic (witnessing a slight reduction of the exposure in 2001 and 2002) [14], reduced exposure to nitrates was recorded for also the Slovak Republic. Nitrate intake calculated based on average concentrations dropped by almost 0.57 $mg.kg^{-1}$ body weight per day as compared with 1990 (a reduction by almost 27%), intake calculated based on median concentrations

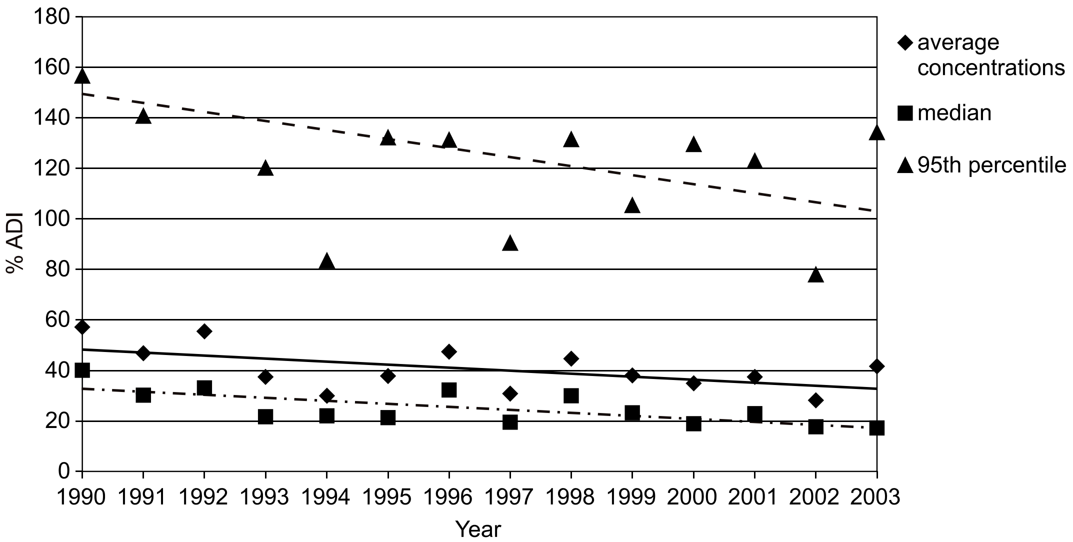

Fig. 3. Trends of nitrate exposure within 1990–2003.

dropped by less than 1 mg.kg^{-1} body weight per day (an almost 57% reduction), and that calculated using the 95th percentile became reduced by approximately 1 mg.kg^{-1} body weight per day (i.e. by approximately 14%).

The estimated nitrate exposure upon the population within 1990–2003 (Fig. 3) shows an oscillating pattern, which may be due to the structure and the seasonality of agricultural commodities. The overall trend of the nitrate exposure doses however suggests a slight reduction of the exposure.

CONCLUSION

Our results suggest that the average nitrate exposure upon the population of our country was relatively low within 1990–2003, with an overall tendency to a slight reduction. A comparison of exposure doses calculated using median nitrate concentrations in specific foods, beverages and water with ADI values showed the average nitrate exposure at the 57.1% ADI level in 1990, dropping to as little as 41.6% ADI in 2003. Based on median concentrations, the exposure estimates gave smaller values, between 40.0% in 1990 and 17.2% in 2003. Higher values for the exposure were only obtained using the 95th percentile; such result is however significantly overestimated. A heavier exposure may actually concern vegetarians due to their consumption of plant products at levels which exceed the average statistical consumption; this however is but a theoretical assumption which was not the subject of our study.

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