ASSESSMENT OF NATURAL RADIOACTIVITY OF SALT SAMPLES WITH REDUCED SODIUM CONTENT

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Abstract

Poles are the leaders in Europe in terms of the amount of salt consumed per day. Table salt is the most frequently used spice and is essential for the proper functioning of the body. However, its excessive consumption may have adverse effects on human health. The Word Health Organization (WHO) informs that the leading cause of premature deaths in the European region of WHO is the cardiovascular disease. This is why medicine is increasingly recommending the use of low-sodium salt, which contains a reduced content of sodium and an increased content of potassium because it is essential for the proper functioning of the brain, cells and for proper work of muscles. There is no information in the literature on the concentration of natural radioactive isotopes present in sodium-reduced salts used as a substitute for table salt. Therefore the aim of this study was establishing the concentration of natural radioactive isotopes in salt samples with low sodium content available in retail sale on the Polish market and widely used in Polish households. In these salt samples analysed was the concentration of natural radioactive isotopes like radium, thorium and potassium with use of Mazar type gamma radiation spectrometer connected with a scintillation probe NaI (Tl). Concentration of ^{226}Ra and ^{232}Th isotopes in the tested salt samples with reduced sodium content amounted to below the background level of determination, and the ^{40}K content was within the limits 3386–5794 Bq·kg^{-1}. Additionally on the basis of the established concentration of natural radioactive isotopes, the annual loading effective dose was calculated for women and men classified to the group of adults from the point of view radiological protection. The effective dose limit of 1 mSv·y-1 was not exceeded for any test subject consuming reduced sodium salts.. The obtained results were compared with reported data from other countries available in the literature.

Keywords: salt substitute with low content of sodium (LSSS), ionizing radiation, Mazar spectrometer, annual committed absorbed dose

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1. Introduction

Poland is a leader in Europe in terms of table salt consumption, which is used as an additive to many dishes and is an component of different food products like pasta (2.8–4.1g·100g $^{-1}$), pizza (7-12.8 g ·100g $^{-1}$), kebab (4.0–8.4 g·100g $^{-1}$), and many others (Surma et al., 2021; Surma, Szyndler et al., 2020; Surma, Romańczyk et al., 2020). The main composition of salt is chlorine anion and soda anion (Jaworska, Siepak, 2018). A diet poor in sodium (mainly chlorine sodium) and in potassium leads to blood pressure development, and this can be a cause to heart attack, stroke or other cardiovascular diseases. The latest data presented in the WHO Report (WHO, 2024) shows that heart diseases are the leading cause of premature death in the European region WHO, which covers 53 countries – mainly from Europe but also partly from Asia. These diseases are responsible for 42.5% of all deaths, i.e. 10 000 a day. The dependency between table salt consumption and blood pressure was presented in papers of various authors (Meneton et al., 2005; Stolarz-Skrzypek & Kawecka-Jaszcz, 2009). According to them the decrease of salt consumption of about 6 g per day causes for instance a reduction of stroke risk by 30% and ischemic heart disease by 25% (Czerwińska & Czerniawska, 2007). In order to reduce the risk of chronic diseases WHO recommends reducing salt consumption to the level in which daily sodium intake by an adult is not higher than 2000 mg, and potassium – not lower than 3510 mg (WHO, 2012). One of the possibilities of lowering the mean sodium consumption of the population is the use of salt substitutes with low sodium content (LSSS), which contain a lower concentration of sodium as an effect of its replacement by potassium or other minerals. Using LSSS salt containing potassium may also be beneficial in reducing sodium consumption and at the same time increasing potassium intake (Zhang et al., 2023). The research of Brand et al. (2022) has shown that as compared with normal salt, LSSS salt causes an increase in potassium content in blood of ca. 0.12 mmol·l^{-1} and a decrease of systolic and diastolic blood pressure average of ca. 2.43 and 4.76 mmHg. However, despite the advantage in lowering blood pressure, the use of LSSS salts may also cause hyperkalaemia, as well as affecting increased doses of ionising radiation from the potassium isotope ^{40}K. The average concentration of natural radioactive isotopes ^{226}Ra and ^{40}K in food products are within the range of 0.01–1.16 Bq·kg^{-1} and 45.9–649.0 Bq·kg^{-1}, respectively (IAEA, 2002). On average, the global population receives a total radiation dose of ca. 0.27 mSv each year due to radionuclides of natural origin in the diet (EC JRC, 2019). In the case of salt substitutes, sodium chlorine is most frequently replaced by potassium chloride, which can cause an increase of loading dose of effective ionizing radiation originated from the potassium isotope. Therefore the authors of this paper decided to assess the natural radioactive isotope of radium (^{226}Ra), thorium (^{232}Th) and potassium (^{40}K) in salt substitutes given that they are becoming increasingly popular on the Polish market. Based on the determined concentrations of natural radioactive isotopes, the annual absorbed dose for each from the tested salt substitute was calculated. The results of natural radioactive isotopes concentration in the tested samples were compared with research results of other authors.

2. Materials and methodology

2.1. Sample collection

A total of seven salt samples were purchased from a local supermarket in Poland. Information of the salt samples and their chemical composition according to information placed on the packaging labels are given in Table 1.

Table 1. Detailed information about the salt samples evaluated in the present study

Sample code	Type of salt	Description of salt	Chemical composition	
			Iodine $\mu g \cdot 100g^{-1}$	Potassium $mg \cdot 100g^{-1}$
S1	sea salt	iodized salt with reduced content of sodium	2313	15714
S2	iodized salt	iodized salt with reduced content of sodium	2100	12500
S3	iodized salt	iodized salt with reduced content of sodium	2300	12500
S4	iodized salt	iodized salt with reduced content of sodium	2300	13000
S5	iodized salt	salt with reduced content of sodium with addition of potassium	2300	13100
S6	iodized salt	salt with reduced content of sodium with addition of potassium	2313	15714
S7	iodized salt	salt with reduced content of sodium with addition of potassium	2400	13600

2.2. Sample preparation and measurement

Samples were dried at a temperature 105°C for 24 hours to obtain dry mass and then sieved through sieves with a fraction of 2 mm. After such preparation the samples were then placed in the Marinelli type measuring container of a 1.7 dm^3 volume, and then concentrated using a shaker. The containers were filled in such a way that the tested material was 5 mm below its upper edge. After packaging and weighing, the samples were hermetically closed. Additionally the containers were wrapped with PCV tape to avoid the losses of ^{222}Rn, which is a volatile product of

^{226}Ra decay (Instytut Techniki Budowlanej, 2010). The measurement time of each sample was 60 000 s. Limit of quantification of the method for samples with very low activity at time of measure of 60 000 s, amounted to 20 Bq·kg^{-1}, 2 Bq·kg^{-1} and 2 Bq·kg^{-1} for ^{40}K, ^{226}Ra and ^{232}Th, respectively. Samples prepared in this way were left for 4 weeks to establish the radioactive balance between ^{226}Ra and ^{214}Bi as well as ^{232}Th and ^{208}Tl. Measurements were performed 3 times for each sample in the same measurement geometry, and the obtained results are an arithmetic mean of three measurements.

Samples of salt substitutes were tested in a three-channel gamma-ray spectrometer Mazar type connected to the scintillation probe NaI(T1) "2x2". The measuring set consists of a scintillation detector with crystal Nal(Tl), with dimensions of 75x75 mm and a resolution of 7.5 (for gamma ray 662 keV) and a spectrometric track. The spectrometric track is composed with a high voltage power supply, an amplifier, three single-channel analyser and three conversion factors. The detector was placed in a protective housing built of lead bricks and additional covers of cadmium, copper and iron to minimize background radiation. As a result of the measurement, the following three numbers were obtained corresponding to counts in potassium, radium and thorium channels. In each of these channels a signal was recorded (counts number) with radiation intensity originating from an isotope. To assume the concentration of natural isotopes of ^{40}K, ^{226}Ra and ^{232}Th, gamma radiation lines were analysed originating from ^{40}K, ^{214}Bi and ^{208}Tl isotopes in the three measurement ranges. Table 2 presents information on particular measurement channels.

Table 2. Ranges of energy and measurement channels (Kurek et al., 2023; Lewicka et al., 2022)

Name of the canal	Isotope	Energy	Range of energy	
			from	to
Potassium (K)	^{40}K	1.46 MeV	1.26 MeV	1.65 MeV
Radium (U)	^{214}Bi	1.76 MeV	1.65 MeV	2.30 MeV
Thorium (Th)	^{208}Tl	2.40 MeV	2.30 MeV	2.85 MeV

Calibration of the detector efficiency was based on measurements of three volume calibration standards: ^{40}K, ^{226}Ra and ^{232}Th and on a measurement of the standard matrix as a background measurement. Ten calibration indexes needed to assess the radiation contents of potassium ^{40}K, ^{226}Ra radium and thorium ^{232}Th were calculated using the matrix method (ITB, 2010; Kurek et al., 2023; Lewicka et al., 2022).

3. Results and discussion

3.1. Concentration of ^{226}Ra, ^{232}Th and ^{40}K

Table 3 presents results of the natural concentration of radioactive isotopes in tested samples of table salt substitutes. An analysis of the study results allows the observation that the concentrations of radium and thorium isotopes are below the level of determination. The concentration of potassium isotope for studied samples was within the range from 3386 $Bq \cdot kg^{-1}$ for sample S7 to 5794 $Bq \cdot kg^{-1}$ for sample S1, whereas the mean value of ^{40}K concentration for all tested samples amounted to 4359 $Bq \cdot kg^{-1}$. The highest value of ^{40}K activity concentration refers to hyposodic iodized salt characterized by low sodium, high potassium chloride and potassium iodate total content.

Table 3. Concentrations of natural radiative isotopes in the tested samples of table salt substitutes

Sample code	Concentration of natural isotopes ($Bq \cdot kg^{-1}$)		
	^{226}Ra	^{232}Th	^{40}K
S1	BDL*	BDL	5794 ± 308
S2	BDL	BDL	3996 ± 220
S3	BDL	BDL	4456 ± 242
S4	BDL	BDL	3621 ± 201
S5	BDL	BDL	3826 ± 212
S6	BDL	BDL	5436 ± 290
S7	BDL	BDL	3386 ± 190
MIN	-	-	3386
MAX	-	-	5794
Mean±SD	-	-	4359 ± 925

**below detection limit (BDL)*

The obtained results of natural radioactive isotope concentrations of salt substitute samples were compared to the results of different salt types studies (i.e. rock salt, Himalayan salt, salt from the Dead Sea, etc.) achieved by the other authors (Table 4).

Table 4. Comparison of radioactivity concentrations for various types of salt from present work and published data

Country	Type of salt	Investigated sample	Concentration of isotopes (Bq·kg^{-1})			Source
			^{226}Ra	^{232}Th	^{40}K	
Malaysia	processed	table salt	3.49±0.09	1.26±0.33	45.61±0.94	(Abdul Sani et al., 2022)
Cyprus	Cyprus black	table salt	-	-	1760±160	(Caridi et al., 2019)
England	processed	sea salt	BDL*	BDL	1490.00±0.12	(Caridi et al., 2019)
Himalayas	processed	table salt	-	-	890±70	(Caridi et al., 2019)
Italy	hyposodic iodized	table salt	-	-	12100±1100	(Caridi et al., 2019)
Egypt	natural	table salt	14.54±0.02	5.95±0.05	4.25±0.05	(El-Bahi, 2003)
Dubai	processed	table salt	BDL	BDL	782.4018	(Hameed et al., 2016)
Iran	processed	table salt	BDL	BDL	5204.00	(Hameed et al., 2016)
Turkey	processed	table salt	5.56	11.73	292.717	(Hameed et al., 2016)
Jordan	processed	Dead Sea salt	2.00±1.00	9.00±5.00	82.00±57.00	(Shaltout, et al., 2017)
Pakistan	natural	rock salt	0.79±0.26	0.64±0.16	23.00±6.00	(Tahir, Alaamer, 2008)
Cyprus	processed	table salt	9.00±0.91	4.23±0.96	63.46± 4.11	(Zeynep, Tufan, 2017)
Iran	processed	table salt	11.34±1.31	3.90±0.41	3152.30±21.61	(Zeynep, Tufan, 2017)
Italy	processed	table salt	7.31±0.96	4.08±1.00	61.09±4.92	(Zeynep, Tufan, 2017)
Poland (Kłodawa)	natural	rock salt	BDL	BDL	66±23	present study

**below detection limit* (*BDL*)

Comparing the obtained results of salt substitutes to results of other authors it was found that the mean concentration ^{40}K for 7 tested samples amounted 4359±925 Bq·kg^{-1} and is lower than its concentration in the salt originating from Iran, i.e. 5204.00 Bq·kg^{-1}. Higher ^{40}K concentrations in relation to tested samples of salt substitutes are presented in scientific papers (Tahir & Alaamer, 2008; Zeynep & Tufan, 2017; El-Bahi, 2003; Shaltout et al., 2017; Caridi et al., 2019; Hameed et al., 2016; Abdul Sani et al., 2022) and the values of ^{40}K concentrations in them are lower in relation to the tested salt substitutes. Additionally, in this paper an assessment was made of the concentration of rock salt extracted from the Polish mine in Kłodawa.

In the case of this rock salt sample, the concentration of radium and thorium isotopes was below the level of determination. Meanwhile the mean concentration of ^{40}K was comparable to samples originating from Cyprus and Italy (Zeynep, Tufan, 2017). The mean concentrations of radium and thorium isotopes for salt samples determined by scientific studies are within the range of 0.79–14.54 Bq·kg^{-1} and 0.64–9.00 Bq·kg^{-1} , respectively. The highest concentration of the ^{226}Ra isotope was determined for the natural rock salt sample originating from Egypt, i.e. 14.54±0.02 Bq·kg^{-1}, and the lowest measurable concentration of ^{226}Ra was found for a salt sample from Pakistan, which was on the level 0.64 Bq·kg^{-1}. The values of radium and thorium concentrations were below natural level of radioactive background, i.e. below level of determination for samples originated from Great Britain, Iran and the United Arab Emirates. The concentration of ^{40}K isotope in salt substitutes with a low content of sodium is higher than in the case of rock salts, Himalaya salts and iodine salts because sodium cation is replaced by the potassium cation. Additionally, the authors of this paper assessed the correlation coefficient (r) between the concentration of iodine and potassium and radioactive concentration of ^{40}K in the studied samples of salt substitutes. Values of correlation coefficients have been shown in the Table 5. Based on the determined coefficients it is possible to observe a positive correlation between concentration of K and ^{40}K.

Table 5. Correlation coefficients (r) between concentration of potassium and iodine and content of ^{40}K in studied samples of salt substitutes

Variables	Concentration		
	^{40}K	*I*	*K*
^{40}K	1		
I	0.0158	1	
K	0.8092	0.3717	1

3.2. Annual committed effective dose for food

For the assessment of human exposure to ionising radiation from oral absorption of specific radionuclides, the annual committed effective dose is determined from equation (1) (Caridi et al., 2019)

$$D = A_C \cdot I_R \cdot D_F \quad (1)$$

where:
D [Sv·y^{-1}] – annual committed effective dose for food salt ingestion;
A_C [Bq·kg^{-1}] – activity concentration of radionuclides in the ingested salt;
I_R [kg·y^{-1}] – annual intake of salt;
D_F [Sv·Bq^{-1}] – dose conversion factor taken from IAEA (ICRP, 1996)

Table 6 presented values of conversion coefficients for natural radioactive isotopes of radium, thorium and potassium supplied to organisms by oral route. The evaluation of human health risk stemming from ingestion of investigated samples for age categories lower than 17 years was not performed, because for the age category of less than 24 months, the ingestion of food salt is not recommended, and for the age category between 24 months and 17 years, the daily intake depends on the child needs (Caridi et al., 2019).

Table 6. Dose conversion factor (D_F) for ^{226}Ra, ^{232}Th and ^{40}K (ICRP,1996)

Isotope	D_F [$Sv \cdot Bq^{-1}$] Adult ≥ 17 years
^{226}Ra	$2.8 \cdot 10^{-7}$
^{232}Th	$2.3 \cdot 10^{-7}$
^{40}K	$6.2 \cdot 10^{-9}$

The average salt intake by women in Poland is 10 g per a day, and by men 13.3 g per day (Surma et al., 2021), which suggests that women consume 3.650 kg and men 4.855 kg of salt every year. With the use of equation (1) the annual committed dose effective for adults was calculated with a division by gender in regard to different annual amount of consumed salt. Table 7 presents results of calculations of annual committed effective dose received by adults due to low sodium salt consumption.

Table 7. Annual committed effective dose for adults (women and men) originating from intake of natural radioactive isotopes by oral route

Sample code	Annual committed effective dose [$mSv \cdot y^{-1}$]	
	Woman (Age ≥ 17 years)	Man (Age ≥ 17 years)
S1	0.131±0.007	0.174±0.009
S2	0.090±0.005	0.120±0.007
S3	0.101±0.005	0.134±0.007
S4	0.082±0.005	0.109±0.006
S5	0.087±0.005	0.115±0.006
S6	0.123±0.007	0.164±0.009
S7	0.077±0.004	0.103±0.006
MIN	0.077	0.103
MAX	0.131	0.174
Mean ± SD	0.099±0.008	0.131±0.010

The average annual committed effective dose received in effect of table salt substitute consumption amounts to 0.099±0.008 mSv·y^{-1} and 0.131±0.010 mSv·y^{-1}, for women and men, respectively. While according to data presented in the Report of UNSCEAR 2000 the mean annual committed effective dose received globally by the general population in the effect of natural radioactive nuclides consumption amounts to 0.29 mSv·y^{-1} (Charles, 2001). Consequently, consumption of food salt substitute as a spice is a source of 34 and 45% of total annual committed effective dose originating from natural radionuclides respectively for women and men, which is the oral intake to the body. In this calculation unprocessed food products like tomatoes, bananas, nuts and others which also contain high concentration of isotope ^{40}K have not been taken into consideration. Therefore, the consumption of a food salt substitute as a condiment makes a significant contribution (i.e. 34% for women and 45% for men) to the total annual effective dose from natural radionuclides entering the body via the oral route. v The low sodium salt recommended by doctors contains potassium that helps blood pressure regulation, and is frequently enriched in iodine, essential for proper thyroid function but on the other hand it contains a much higher concentration of ^{40}K than the other types of salt. Therefore it should be used in limited quantity so as not to expose people to additional doses of ionizing radiation.

Conclusions

The aim of this paper was to assess the concentration of natural radioactive isotopes of radium, thorium and potassium in seven samples of food salt with a decreased content of sodium. There is a lack of information on this subject in the literature and in the Polish bibliography. Our research was performed on a Mazar type gamma radiation spectrometer, connected with a scintillation probe NaI(Tl). Values of ^{226}Ra and ^{232}Th isotope concentrations for all samples were lower than the detection level. On the other hand, the concentrations of isotope ^{40}K contained in the range 3386–5794 Bq·kg^{-1}. The average concentration of potassium ^{40}K in the Earth crust amounts 400 Bq·kg^{-1},which suggests that its content in tested salt samples with decreased sodium quantity is increased. For the studied samples additional calculations were carried out of the loading effective dose to which adults are exposed in a division into women and men. The obtained annual committed effective dose is under the allowable level (1 mSv·y^{-1}) (ICRP, 1996) for all investigated samples and therefore there is no risk of ionizing radiation effects on humans. Data generated in this study will provide baseline values of annual committed effective dose stemming from ingestion of natural radionuclides in salt samples. The data may also prove to be helpful in assessing the effective radiation doses from naturally occurring radionuclides received by the population from the intake of salt samples.

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References

1. Abdul Sani, S.F., Muhamad Azim, M.K., Marzuki, A.A., Khandaker, M.U., Almugren, K.S., Daar, E., Alkallas, F.H., Bradley, D.A., (2022). Radioactivity and elemental concentrations of natural and commercial salt. *Radiation Physics and Chemistry*, vol. 190, 109790. doi:10.1016/j.radphyschem.2021.109790
2. Brand, A., Visser, M.E., Schoonees, A., Naude, C.E., (2022). Replacing salt with low-sodium salt substitutes (LSSS) for cardiovascular health in adults, children and pregnant women (Review). *Cochrane Database of Systematic Reviews,* Issue 8, Art. No. Cd015207.
3. Caridi, F., Messina M., Belvedere, A., D'Agostino, M., Marguccio, S., Settineri, L., Belmusto, G., (2019). Food salt characterization in terms of radioactivity and metals contamination. *Applied Sciences,* 9, 2882. DOI: 10.3390/app9142882
4. Charles, M., (2001). UNSCEAR Report 2000: sources and effects of ionizing radiation. *Journal of Radiological Protection,* vol. 21(1), pp. 83–86. doi: 10.1088/0952-4746/21/1/609. PMID: 11281539
5. Czerwińska, D., Czerniawska, A., (2007). Ocena spożycia sodu, z uwzględnieniem soli kuchennej jako jego źródła, w wybranej populacji warszawskiej (Assessment of sodium intake, taking into account table salt as its source, in a selected Warsaw population). *Roczniki Państwowego Zakładu Higieny (Annals of the National Institute of Hygiene)*, vol. 58, no. 1, pp. 205–210. (in Polish)
6. El-Bahi, S.M., (2003). Radioactivity levels of salt for natural sediments in the north-western desert and local markets in Egypt. *Applied Radiation and Isotopes*, vol. 58, pp. 143–148. doi: 10.1016/S0969-8043(02)00270-1
7. European Commission, Joint Research Centre, (2019). *European Atlas of Natural Radiation*. *Chapter 7.* Luxembourg: Publications Office of the European Union.
8. Hameed, B.S., Rejah, B.K., Muter, S., (2016). Study the concentration of naturally occurring radioactive materials in the samples of rice and salt in Baghdad Governorate. *Journal of Al-Nahrain University*, vol. 19 (1), pp. 104–109. doi: 10.22401/JNUS.19.1.13
9. Instytut Techniki Budowlanej, (2010). *Poradnik Instytutu Techniki Budowlanej nr 455/2010 Badania promieniotwórczości naturalnej wyrobów budowlanych* (*Handbook No. 455/2010. Testing of natural radioactivity of construction products*). Warsaw: ITB. (in Polish)
10. International Atomic Energy Agency, (2002). *Natural and inducted radioactivity in food (IAEA-TECDOC-1287).* Vienna, Austria: Food and Environmental Protection Section, International Atomic Energy Agency.
11. International Commission on Radiological Protection, (1996). *ICRP Publication 72. Age–dependent doses to members of the public from intake of radionuclides: Part 5. Compilation of ingestion and inhalation dose coefficients.*, Oxford, UK: Pergamon Press.
12. Jaworska, J., Siepak, M., (2018). Polish rock salts vs Himalayan salts – comparative analysis of selected components of table salts. *Przegląd Solny / Salt Review*, vol. 14, pp. 95–104.

13. Kurek, K., Isajenko, K., Piotrowska, B., Łukaszek-Chmielewska, A., Lipiński, P., (2023). Impact of legislative change on the classification of raw materials and building materials in terms of natural radioactivity. *Zeszyty Naukowe SGSP*, No. 88 (1), pp. 211–231. doi: 10.5604/01.3001.0054.1459
14. Lewicka, S., Piotrowska, B., Łukaszek-Chmielewska, A., Drzymała, T., (2022). Assessment of natural radioactivity in cements used as building materials in Poland. *International Journal of Environmental Research and Public Health,* 19, 11695. doi: 10.3390/ijerph191811695
15. Meneton, P., Jeunemaitre, X., de Wardener, H.E. et al., (2005). Links between dietary salt intake, renal salt handling, blood pressure, and cardiovascular diseases. *Physiological Reviews,* vol. 85, no. 2, pp. 679–715. doi:10.1152/physrev.00056.2003
16. Shaltout, A.A., Sameh, I.A., Abayazeed, S.D., El-Taher, A., Abd-Elkader, O.H., (2017). Quantitative elemental analysis and natural radioactivity levels of mud and salt collected from the Dead Sea, Jordan. *Microchemical Journal*, vol. 133, pp. 352–357. doi: 10.1016/j.microc.2017.03.055
17. Stolarz-Skrzypek, K., Kawecka-Jaszcz, K., (2009). Ograniczenie spożycia soli kuchennej jako metoda prewencji nadciśnienia tętniczego (Limiting the consumption of table salt as a method of preventing hypertension, Progress in Medicine). *Postępy Nauk Medycznych*, vol. 1, pp. 34–38. (in Polish)
18. Surma, S., Romańczyk, M., Bańkowski, E., (2020). The role of limiting sodium intake in the diet — from theory to practice. *Folia Cardiologica*, vol. 15, no. 3, pp. 227–235.
19. Surma, S., Romańczyk, M., Szyndler, A., Narkiewicz, K., (2021). Sól a nadciśnienie tętnicze — od epidemiologii przez patofizjologię do istotnego problemu cywilizacyjnego (Salt and hypertension – from epidemiology through pathophysiology to a significant civilization problem, Arterial Hypertension). *Nadciśnienie Tętnicze w Praktyce*, vol. 7, no. 1, pp. 19–27. (in Polish)
20. Surma, S., Szyndler, A., Narkiewicz, K., (2020). Salt and arterial hypertension — epidemiological, pathophysiological and preventive aspects. *Arterial Hypertension*, vol. 24, no. 4, pp. 148–158.
21. Tahir, S.N.A., Alaamer, A.S., (2008). Determination of natural radioactivity in rock salt and radiation doses due to its ingestion. *Journal of Radiological Protection*, 28, pp. 233–6. doi: 10.1088/0952-4746/28/2/N01
22. World Health Organization, (2024). *Action on salt and hypertension: reducing cardiovascular disease burden in the WHO European Region*. WHO Regional Office for Europe. ISBN: 978-92-890-6081-3 (PDF).
23. World Health Organization, (2012). *Guideline: Potassium Intake for Adults and Children*. Geneva, Switzerland: World Health Organization (WHO).
24. World Health Organization, (2012). *Guideline: Sodium Intake for Adults and Children.* Geneva, Switzerland: World Health Organization (WHO).
25. Zeynep, Y., Tufan, M.C., (2017). Determination of radioactivity levels of salt minerals on the market. *Canadian Journal of Physics*, 96 (7), pp. 784–785. doi: 10.1139/cjp-2017-0775
26. Zhang, P., Fan, F., Li, Y., Li, Y., Luo, R., Li, L., Zhang, G., Wang, L., Jiao, X., He, F.J., (2023). Awareness and use of low-sodium salt substitutes and its impact on 24-h urinary sodium and potassium excretion in China-A Cross-Sectional Study. *Nutrients*, no. 15, 3000.