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Deterministic and probabilistic assessment of nitrate exposure from selected fruits and vegetables consumption in Armenia

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Abstract. This study aimed to evaluate dietary exposure to nitrate via consumption of popular fruits and vegetables produced in Armenia. The analytical data for a total of 158 fruits and vegetables were taken from the National Residue Monitoring Program's data of 2021. To assess nitrate exposure, two scenarios were implemented using: 1) the National Household survey data related to consumption rates of investigated fruits and vegetables, and 2) existing individual-based consumption data for the portion. To characterize risks of daily intake of nitrates, the deterministic and probabilistic (Monte Carlo simulation via @RISK software) approaches were considered. According to deterministic assessment under both scenarios, daily intake of nitrates via the examined fruits and vegetables did not exceed the Acceptable Daily Intake (ADI), as well as the Hazard Quotient (HQ < 1) and Hazard Index (HI < 1). This research has indicated that for adult consumers, out of all the examined fruits and vegetables, peaches, apples, and potatoes are the major contributors to nitrate exposure 18%, 14%, and 13%, respectively. No leafy vegetables and other sources (soil, water, meat products) were included in this research. Nevertheless, the Probability of Exceedance (POE) of ADI was 0.02% for the daily intake on an individual basis, simulating the probability of exposure to nitrates. This research provides the relevant data on nitrates in regionally grown and consumed fruits and vegetables. The findings of this research provide a solid scientific foundation for national authorities to make evidence-based decisions in making targeted monitoring plans to control nitrate concentration.

Key words: daily intake, fruits, health risk, Monte Carlo simulation, nitrates, vegetables.

INTRODUCTION

Nitrates are chemical compounds that are naturally formed in the environment by the nitrogen cycle in the atmosphere with the help of different groups of microorganisms. These compounds can be found everywhere: in the air, soil, water, plants, and in food (Gassara et al., 2016; Bhattacharya et al., 2024). In addition to nitrates from natural fixation, synthetic nitrates are formed from fertilizers (Hord et al., 2009; Cui et al., 2020; Liu et al., 2020). They are also used as food additives and dietary supplements (Wikoff et al., 2018; Karwowska & Kononiuk, 2020). Nitrates are an integral part of the human diet, and the main sources of these compounds are vegetables, fruits, cured/flavored

meat, dairy products, and drinking water (IARC, 2017; IARC, 2017; Wikoff et al., 2018; Kalaycıoğlu & Erim, 2019; Karwowska & Kononiuk, 2020; Shakil et al., 2022; Anyimah-Ackah, 2025; Bowles et al., 2025). As declared by several researchers (Hord et al., 2009; Bahadoran et al. 2016; Anyimah-Ackah, 2025), the major sources of nitrate exposure are vegetables: nearly 80% of dietary nitrate intake is attributed to them. Over recent decades, controversial opinions have been formed regarding the effects of nitrate exposure on human health (Hord et al., 2009; Wikoff et al., 2018). On the one hand, natural/added nitrates prevent cardiovascular diseases (Hord et al., 2009; Ghasemi et al., 2024) and enhance metabolic and neurocognitive health (Apte et al., 2024; Bowles et al., 2025). In addition, according to some studies, nitrates may help reduce the risk of obesity and diabetes (McNally et al., 2016) and are considered to have low toxicity in humans (Cheng et al., 2021).

The International Agency for Research on Cancer (IARC) has declared that nitrates are probably carcinogenic to humans (Group 2A) as a result of endogenous nitrosation (IARC, 2017). The toxic effects of high-level ingested nitrates are due to their endogenous conversion to nitrites and the formation of N-nitroso compounds (NOCs) in the digestive tract, which are considered as potential carcinogens in humans (Gassara et al., 2016; IARC, 2017; Chazelas et al., 2022; Bowles et al., 2025; Udayamathi et al., 2025). Therefore, to regulate the levels of dietary nitrates/nitrites in food the European Commission (EC) set a maximum level for preserved, deep–frozen, or frozen spinach and fresh lettuce from 2000 to 4,500 mg NO_3 kg^{-1} with due regard to the harvesting period (Commission Regulation (EU), 2023) and the Environmental Protection Agency (EPA) lists maximum contaminant levels (MCL) and maximum contaminant level goals (MCLG) of 10 mg L^{-1} for nitrates in drinking water (US EPA, 2018). The European Food Safety Authority (EFSA) has set an acceptable daily intake (ADI) for nitrates equal to 3.7 mg kg^{-1} per day (EFSA, 2008, 2018). In terms of nitrate exposure assessment, the benefits of nitrates and the health risks posed by these compounds are controversial. An attempt to somehow clarify such controversy was made by the EC–funded project 'Benefit–Risk Analysis for Foods (BRAFO) (Hoekstra et al., 2012). Due to the BRAFO project, the assessment of nitrates in food became more accurate and complete, highlighting the variability and uncertainties of nitrate exposure assessment (Kalaycıoğlu & Erim, 2019; Wikoff et al., 2018; Cheng et al., 2021). Therefore, to assess nitrates, this benefit-risk methodology recommends using the Tier approaches and probabilistic methods whenever required (Hoekstra et al., 2012). When evaluating a dietary exposure of nitrates through a BRAFO framework, Wikoff et al. 2018 suggest the ADI ~12–17 mg kg^{-1} per day, as the benefits of dietary intake of nitrates commonly outweigh the risks.

Armenia is a country with developing agriculture, and as with similar states, it also uses fertilizers in agricultural practice and in food production as food additives. However, the current status of nitrates is unclear country-wide. According to estimations, annually local farmers and large landowners use some 30,000–40,000 tons of ammonium nitrate (Harutyunyan et al., 2022). The standards and regulations set for agricultural products in Armenia include the national and the Customs Union Commission's technical regulations (TR CU) of a Maximum Allowable Concentration (MAC) of nitrates in fruits – 60 mg kg^{-1}, and in vegetables – 80 to 1400 mg kg^{-1} (Government Decision, 2006; TR CU 021/2011, 2011).

In areas with intensive agriculture, the nitrate content in river waters was increasing in parallel with the intensification of water flow (Galstyan et al., 2023), so to protect water resources from nitrate pollution caused by agricultural activities in 2024, a relevant order was issued by the Armenian Government (Order, 2024). That was a significant step in controlling nitrate content in river waters and the cyclic movement of these compounds into drinking water. Our previous research based on data from the National Governmental program of the Republic of Armenia: 'Implementation of monitoring of pesticides, nitrates, heavy metals residues and genetically modified organisms in products of plant origin' indicated no health concern via pesticides (chlorpyrifos) (Beglaryan et al., 2025) consumption through vegetables (tomato and cucumber) and that, among heavy metals, only lead raises consumer safety concerns via food groups (Pipoyan et al., 2023). At the same time, ensuring the consumption of sufficient amounts of fruits and vegetables are an important component of a healthy diet. The Food and Agricultural Organization (FAO) and the World Health Organization (WHO) recommend a daily consumption of at least 400 g of fruits and vegetables (FAO, 2021). However, recent findings showed that fruit and vegetable daily consumption by the Armenian population doesn't meet the WHO recommendations. Meanwhile, potato consumption was nearly 31%, with an average intake of approximately 200 g (Pipoyan et al., 2026).

Despite controlling mechanisms, there remains limited information on nitrate residues in food, particularly fruits and vegetables, and, critically, a lack of comparative exposure assessments using both household and individual consumption data. Furthermore, data on nitrate exposure in specific consumer groups in Armenia, particularly adults, are scarce, restricting targeted risk assessments. There are also concerns that levels of nitrates in fruits and vegetables may pose health risks. Since these data are lacking, we attempted to determine whether there are exposure levels above the MAC that could pose health risks or not. Hence, the incentive for this research was to conduct the first systematic dietary exposure assessment for nitrates within the consumers, highlighting adults, applying a deterministic and a probabilistic modelling approach via Monte Carlo simulation, and critically evaluating results based on household data and individual consumption data. This is a preliminary study intended to support future work on dietary nitrate exposure in Armenia and to provide scientific evidence that can assist the competent authorities in strengthening and improving national monitoring programs. Also, these research findings fill the data gaps for nitrates both in Armenia and the South Caucasian region and provide a robust base for the national food safety authorities to manage low and high risks and implement targeted monitoring plans to reduce nitrate exposure in case of necessity.

MATERIALS AND METHODS

Laboratory analysis

The chemical concentration data of nitrates were taken from the National Governmental program of the Republic of Armenia: 'Implementation of monitoring of pesticides, nitrates, heavy metals residues and genetically modified organisms in products of plant origin'. The laboratory analysis data of nitrates in fruits and vegetables were conducted at the Republican Veterinary–Sanitary and Phytopathology Center of

Laboratory Service (RVSPCLS) SNCO accredited internationally by ISO 17025. The fruit and vegetable composite samples were collected in 2021 from large agricultural plots (Beglaryan et al., 2025). A total of 158 samples were collected, of which 62 were fruits, 12 were fruity vegetables, 75 were vegetables, and 9 were beans. Each composite sample consists of at least 12 sub-samples to ensure the representativeness of the primary production sources. The concentrations of nitrates were analyzed by potentiometric methodology in accordance with interstate standard GOST 34570–2019 (Fruits, vegetables and derived products–Determination of nitrate content by potentiometric method) (GOST 34570–2019, 2019).

Dietary intake estimation and risk characterization

Dietary intake (DI) of nitrates was estimated by equation (1):

$$DI = \frac{C \times CR}{BW} \quad (1)$$

where C – the nitrate concentration in analyzed fruit and vegetable samples (mg kg^{-1}); Taking into consideration that during different cooking processes (peeling, boiling, frying, etc.) the concentration of nitrates can decrease, the reduction factor for potato of 0.5 (EFSA, 2008) was also used to reduce the overestimations. CR – the consumption rate (kg day^{-1}); BW – body weight (kg).

This research assumed the average BW in household scenario as 71.5 kg (Pipoyan et al., 2023). In the individual-based scenario, for each consumer, the individual BW was used. Consumption rates were taken from the available and officially published National household consumption database for 2021 from the Statistical Committee of the Republic of Armenia (ArmStat, 2022). The household consumption database was conducted on nationally representative samples and provides comprehensive information regarding consumption, income, expenses, consumption of basic food, the existence of long-term goods, affordable health and educational systems, social transfers, etc. (Stepanyan et al., 2022). To obtain daily consumption, the data from the household survey were divided by 30.4 for each food item. The data on individual-based consumption for selected fruits and vegetables were collected through a 24-hour recall survey by FAO methodology (FAO, 2018). The survey was conducted in 2021 among Armenia's adult population (18–80 years old) as part of the State program 20TTCG-4A001 (Pipoyan et al., 2023; Pipoyan et al., 2026) on an anonymous basis. A total of 1,400 participants were interviewed, including all 10 regions of Armenia and the capital city of Yerevan. The survey data included 666 males and 734 females. Each participant was interviewed once by well-trained interviewers. The response rates (n) of investigated food items are as follows: apple n = 233, peach n = 55, apricot n = 139, plum n = 24, cherry n = 154, grape n = 33, watermelon n = 160, melon n = 47, potato n = 443, tomato = 482, cucumber n = 456, pepper n = 80, eggplant n = 33, green beans n = 5. For food-specific dietary intake (DI) calculations, participants reporting zero consumption of a particular food item were coded as missing for that food item. Therefore, non-consumers were excluded from the calculation of the corresponding DI values, and the reported DI values were calculated only among participants who reported consumption of the respective food. The Aggregated DI was calculated for the household scenario only, as the consumption rates of food items were given on a daily basis; meanwhile, in the individual consumption scenario, there wasn't a single consumer who contributed to all investigated foods on a 24–hour recall basis.

The exposure assessment was done by comparing our data with the ADI for nitrates 3.7 mg kg^{-1} body weight per day, set by EFSA (EFSA, 2008).

Risk characterization was built on data obtained under two scenarios: 1) the National household consumption survey and 2) individual-based consumption data.

Risk characterization of nitrates was done by calculating the Hazard Quotient (HQ) and Hazard Index (HI) by following equations (2; 3)

$$HQ = \frac{DI}{HBGVs} \quad (2)$$

where DI – the daily intake of nitrates via different fruits and vegetables, and HBGVs are the health-based guidance values. In this research, the ADI of 3.7 mg kg^{-1} per day was used.

$$HI = HQ_1 + HQ_2 + \cdots + HQ_n \quad (3)$$

where HI – the sum of all HQ. If the obtained results ≤ 1, that shows a low or insignificant level of exposure. While the HI ≥ 1 values, vice versa, show probable risks to human health (Qasemi et al., 2024).

Statistical data treatment

Individual-based consumption survey data input and subsequent data treatment were done with the application of IBM SPSS software (IBM SPSS, v.22). For the POE (Probability of Exceeding) of ADI of estimated daily intake of nitrates to perform, @RISK software (version 8.10.1, Lumivero LLC, Denver, Colorado, USA). Both analytical data on nitrate occurrence in the examined fruits and vegetables and food consumption rates were used as input data for the Monte Carlo simulation. For each participant, food-specific nitrate intakes were calculated using the laboratory-measured nitrate concentration for each food item, the participant-specific consumption amount, and the participant's actual body weight. The resulting food-specific intake values were summed across all food items to obtain the total dietary nitrate intake ∑DI for each participant. The initial simulation was performed using 10,000 iterations and was subsequently repeated using 100,000 iterations to evaluate the numerical stability of the simulation estimates and reduce Monte Carlo sampling error. (Vose, 2008). Participants with a ∑DI equal to zero were excluded from the dataset used for distribution fitting and Monte Carlo simulation. A probability distribution was fitted to the remaining non-zero individual ∑DI values using the @RISK Fit Distribution procedure. Candidate probability distributions available in @RISK were compared using the Akaike Information Criterion (AIC) and the Anderson–Darling (A-D) statistic. The PERT distribution provided the lowest AIC (1450.5583) and the lowest A-D statistic (2.3036) among the evaluated distributions and was therefore selected for the Monte Carlo simulation. For comparison, the next-ranked Pearson5 distribution had an AIC of 1460.0875 and an A-D statistic of 2.3313. For gender-specific comparisons, independent-samples t-tests were used to assess differences in estimated DI values between males and females. Equality of variances was assessed using Levene's test. When Levene's test was not significant ($p > 0.05$), the 'equal variances assumed" results were used; when Levene's test was significant ($p \leq 0.05$), the "equal variances not assumed' results were reported. Two-sided p-values < 0.05 were considered statistically significant.

RESULTS AND DISCUSSION

Nitrates in fruits and vegetables

The analytical results of nitrate residues in a total of 158 samples of fruits (apples, peaches, apricots, plums, cherries, grapes) and vegetables (potatoes, tomatoes, cucumber, pepper, eggplant, watermelon, melon, beans) are given in Table 1. A total of 46.8% of examined fruits exceeded the MACs (Table 1). No vegetable samples exceeded the set MACs (Government Decision, 2006; TR CU 021/2011, 2011) (Table 1).

Table 1. Mean concentrations of nitrates in the examined fruits and vegetables, mg kg^{-1}

	The mac for nitrates (mg kg^{-1})	Number of samples and the percentage of samples exceeded MACs (%)	Mean and SD[1]	Concentration range
Fruits				
Apple	60	1 (6.7)	36 (± 14.8)	10–74
Peach	60	9 (100)	88 (± 13.0)	71–111
Apricot	60	6 (100)	109 (± 11.1)	97–128
Plum	60	6 (83.3)	68 (± 19.8)	30–85
Cherry	60	14 (57.1)	63 (± 11.8)	43–79
Grape	60	12 (0)	26 (± 13.6)	7–48
Watermelon	60	6 (0)	26 (± 5.0)	17–31
Melon	90	6 (0)	67 (± 21.4)	32–89
Vegetables				
Potato	250	29 (0)	116 (± 21.1)	60–153
Tomato	150	20 (0)	53 (± 17.3)	26–95
Cucumber	150	14 (0)	67 (± 19.4)	36–100
Pepper	200	6 (0)	41 (± 14.2)	25–65
Eggplant	-[2]	6 (n.c[3])	36 (± 9.1)	25–46
Legumes				
Green beans	-	9 (n.c)	60 (± 29.8)	13–98
		158 (18.4)	66.5 (± 34.5)	7–153

[1]standard deviation; [2]no data on Maximum Allowable Concentration (MAC); [3]n.c – not calculated because of the absence of MACs.

As shown in Table 1, the mean highest levels of nitrates are observed in vegetables vs. fruits and green beans. Mean levels of nitrates in fruits vary from 26 to 109 mg kg^{-1}. The mean lowest concentrations were found in watermelon and grape, and the highest in apricots. In vegetables, the highest mean concentration was detected in potatoes, and the lowest in eggplant: 36–116 mg kg^{-1}, respectively. The MACs set by the Government of the RA and the Commission of the Customs Union (Government Decision, 2006; TR CU 021/2011, 2011) were exceeded in 29 out of 62 fruit samples. The main cause of varying nitrate concentrations in Armenia's fruits and vegetables is the lack of governmental regulations on the use of organic and non-organic fertilizers after the privatization of agricultural lands (Harutyunyan et al., 2022) and the scarcity of soil fertility studies for a complete vision of the current status of Armenia's agricultural lands to gain (Galstyan et al., 2023). It is relevant to note that concentrations of nitrates in fruits and vegetables vary worldwide, depending on several conditions, e.g., agricultural practices, soil characteristics, fertilizers applied, plant species, climate features, and so

forth (Bian et al., 2020; Uddin et al., 2021; Hosseini et al., 2023). In the neighboring country of Iran, the nitrate mean levels in vegetables vary from 33.32 to 75.99 mg kg^{-1}, the lowest was found in tomatoes and the highest in beet leaf (Salehzadeh et al., 2020). Compared with this research data, the nitrate concentrations in tomatoes were 1.59–fold higher than in Iranian tomatoes. As reported by Hosseini (Hosseini et al., 2023), worldwide, the lowest mean nitrate levels (5.284 mg kg^{-1}) in fruits and vegetables were detected in Europe and Central Asia, the highest (2,366.473 mg kg^{-1}), – in Latin America and the Caribbean countries. According to estimations provided by Hosseini (Hosseini et al., 2023), the mean worldwide concentrations of nitrates in potatoes, tomatoes, cucumbers, peppers, and eggplants are 123.57, 71.42, 224.65, 23.97, and 174.38 mg kg^{-1}, respectively. To compare, the worldwide mean nitrate concentrations of the noted vegetables, except pepper, were 1.06 to 4.8 times higher than those obtained in the frames of our research in Armenia, while pepper was 1.7 times higher in nitrates than the mean worldwide levels of these compounds.

However, such is not the case with fruits. According to worldwide concentrations of nitrates, the mean concentrations in apples, peaches, apricots, grapes, plums, cherries, watermelons and melons make 18.31, 37.20, 91.08, 3.57, 105.85, 35.66, 6.01, and 108.97 mg kg^{-1}, respectively. In this research, mean nitrate levels of the examined fruits, except melon, were 1.1 to 17.65 – times and of melon – 1.63 time higher than those given by Hosseini (Hosseini et al., 2023).

Dietary intake of nitrates, exposure assessment, and risk characterization

The dietary intake (DI) of nitrates by adult consumers was calculated using the national household survey data (ArmStat, 2022) on fruit and vegetable consumption (Table 2). Also, calculations were done of DI of nitrates for male and female consumers.

As seen from Table 2, for adult fruit consumers, the mean DI of nitrates via fruits varies from 0.0003 to 0.0147 mg kg^{-1} per day. The lowest contribution of nitrates is via cherries, and the highest via apples. In vegetable consumers, the mean lowest contribution of nitrates is via pepper (0.0041 mg kg^{-1} per day), the highest – via potato for both raw and with reduction factor data (0.1725 and 0.0863 mg kg^{-1} per day, respectively).

Hence, even the highest nitrate contents in the examined fruits and vegetables don't exceed the ADI set by EFSA (EFSA, 2008) (3.7 mg kg^{-1} bw per day). The mean DI of nitrates via fruits makes 0–0.4% of ADI. As for vegetables, the mean DI makes 0.7–4.7% of ADI. The DI of nitrate intake via legumes makes 0.3% of ADI. The calculated mean HQ by ADI in fruits was in the range of 0.0001 to 0.0040 (Table 2).

An Aggregated DI was calculated with raw food analytical data, as there weren't significant differences, and the results didn't exceed the internationally accepted thresholds. In this household scenario, the HI didn't exceed the threshold of one, and, within the limited scope of this study (no leafy vegetables included), the probability of exceeding the ADI is low even with long-term exposure (EFSA, 2008). DI of nitrates derived from our research was 6.7 times lower as compared with research on the DI of nitrates via fruits and vegetables from high- and low- risk areas in the Islamic Republic of Iran (Ghaffari et al., 2019).

The DI of the second scenario built on the individual consumption survey data is given in Tables 3 and 4.

Table 2. Health risk assessment of adult consumers based on household survey data

	Mean DI, mg kg^{-1} bw day^{-1}	DI range, mg kg^{-1} bw day^{-1}	% of ADI	HQ_ADI
Fruits				
Apple	0.0147	0.0041–0.0303	0.4	0.0040
Peach	0.0081	0.0065–0.0102	0.2	0.0022
Apricot	0.0084	0.0075–0.0098	0.2	0.0023
Plum	0.0025	0.0011–0.0031	0.1	0.0007
Cherry	0.0003	0.0002–0.0003	0.0	0.0001
Grape	0.0033	0.0009–0.0062	0.1	0.0009
Watermelon	0.0103	0.0067–0.0123	0.3	0.0028
Melon	0.0038	0.0018–0.0051	0.1	0.0010
Vegetables				
Potato	0.1725	0.0892–0.2275	4.7	0.0466
Potato	0.0863[1]	0.0446–0.1138	2.3	0.0233
Tomato	0.0272	0.0133–0.0487	0.7	0.0073
Cucumber	0.0282	0.0151–0.0421	0.8	0.0076
Pepper	0.0041	0.0025–0.0065	0.1	0.0011
Eggplant	0.0057	0.0040–0.0073	0.2	0.0016
Legumes				
Green beans	0.0095	0.0020–0.0154	0.3	0.0026
Aggregate DI[2]	0.30	0.16–0.43	-	-
HI	-[3]	-	-	0.08

[1]The reduction factor of 0.5 for potato was used (EFSA, 2008); [2]was calculated considering the raw food data; [3]not applicable.

Table 3. Mean DI and HQ of nitrates by adult consumers based on the individual consumption portion data, mg kg^{-1} bw day^{-1}

	Mean DI, SD[1]	% of ADI	HQ_ADI
Fruits			
Apple	0.37 (± 0.23)	10.0	0.10
Peach	0.49 (± 0.41)	13.4	0.13
Apricot	0.30 (± 0.22)	8.1	0.08
Plum	0.13 (± 0.11)	3.4	0.03
Cherry	0.09 (± 0.07)	2.5	0.02
Grape	0.07 (± 0.03)	1.9	0.02
Watermelon	0.20 (± 0.20)	5.3	0.05
Melon	0.21 (± 0.23)	5.7	0.06
Vegetables			
Potato	0.34 (± 0.14)	9.1	0.09
Potato	0.17 (± 0.07) [2]	4.6	0.05
Tomato	0.13 (± 0.08)	3.5	0.03
Cucumber	0.11 (± 0.08)	3.1	0.03
Pepper	0.06 (± 0.04)	1.6	0.02
Eggplant	0.08 (± 0.05)	2.3	0.02
Legumes			
Green beans	0.12 (± 0.04)	3.2	0.03
HI[3]	-[4]	-	0.73

[1]standard deviation; [2]The reduction factor of 0.5 for potato was used (EFSA, 2008); [3]was calculated considering the raw food data; [4]not applicable.

The nitrate contribution under the second scenario shows that of all the examined fruits, the lowest daily mean intake is through grapes and the highest–via peaches 0.07 and 0.49 mg kg^{-1} per day, respectively. In the case of nitrate consumption through vegetables, the mean lowest DI is via pepper and the highest–via potato 0.06 and 0.34 mg kg^{-1} per day, respectively. In this scenario, the potato processing reduction factor was also considered, and still the potato remains the major contributor in vegetables. In this scenario, the mean DI by fruits makes 1.90% to 13.4% of ADI (Table 3). In vegetables, the DI makes 1.6% to 9.1 of ADI (Table 3). The HI in this scenario didn't exceed the threshold of one calculated by ADI.

Gender-specific comparisons showed statistically significant differences in DI values for apples ($p < 0.001$), potatoes ($p < 0.001$), and total DI ($p = 0.002$).

In this scenario, also were discussed the individual consumption portions of selected fruits and vegetables for male and female consumers. No statistically significant differences between males and females were observed for the other food items ($p > 0.05$). Here, the lowest DI of nitrates for males was through cherries and grapes 0.08 mg kg^{-1} per day, and the highest DI was via peaches 0.5 mg kg^{-1} per day. As for female consumers, the lowest and the highest DIs were via consumption of grapes and peaches 0.06 and 0.49 mg kg^{-1} per day, respectively (Table 4). As in the case of mean individual consumption portion data, here the peppers and potatoes have the lowest and highest DIs for both male and female consumers, respectively. The calculated HI by ADI didn't exceed the threshold value of 1 (Table 4). This once again emphasizes that, in an individual case scenario, the nitrates intake through fruits and vegetables health effects.

Table 4. Mean DI and HQ of nitrates by males and females based on the individual consumption portion data, mg kg^{-1} bw day^{-1}

	Mean DI for male, SD[1]	HQ_male ADI	Mean DI for female, SD	HQ_female ADI
Fruits				
Apple	0.34 (± 0.20)	0.092	0.40 (± 0.25)	0.108
Peach	0.50 (± 0.32)	0.134	0.49 (± 0.44)	0.133
Apricot	0.28 (± 0.21)	0.076	0.31 (± 0.23)	0.084
Plum	0.10 (± 0.10)	0.028	0.14 (± 0.12)	0.038
Cherry	0.08 (± 0.05)	0.023	0.10 (± 0.08)	0.027
Grape	0.08 (± 0.04)	0.023	0.06 (± 0.03)	0.017
Watermelon	0.20 (± 0.18)	0.054	0.19 (± 0.21)	0.052
Melon	0.24 (± 0.31)	0.065	0.18 (± 0.14)	0.050
Vegetables				
Potato	0.31 (± 0.12)	0.085	0.37 (± 0.15)	0.099
Potato	0.16 (± 0.06)[2]	0.042	0.18 (± 0.08)	0.049
Tomato	0.13 (± 0.08)	0.035	0.13 (± 0.09)	0.035
Cucumber	0.11 (± 0.08)	0.030	0.11 (± 0.09)	0.031
Pepper	0.06 (± 0.04)	0.017	0.05 (± 0.03)	0.015
Eggplant	0.09 (± 0.05)	0.024	0.08 (± 0.05)	0.022
Legumes				
Green beans	0.12 (± 0.06)	0.033	0.11 (± 0.04)	0.030
HI[3]	-[4]	**0.72**	-	**0.74**

[1] standard deviation; [2]The reduction factor of 0.5 for potato was used (EFSA, 2008); [3]was calculated considering the raw food data; [4]not applicable.

Collating between the National Household consumption and individual-based surveys' data points towards substantial differences in dietary intake of nitrates via examined fruits and vegetables. This is mainly because household-based estimates are per capita averages over the whole population (including non-consumers), whereas individual-based DIs were calculated for consumers only; in addition, the household methodology does not capture seasonality or actual consumption portions. Contribution of ∑DI of nitrates based on the portion data shown in Fig. 1.

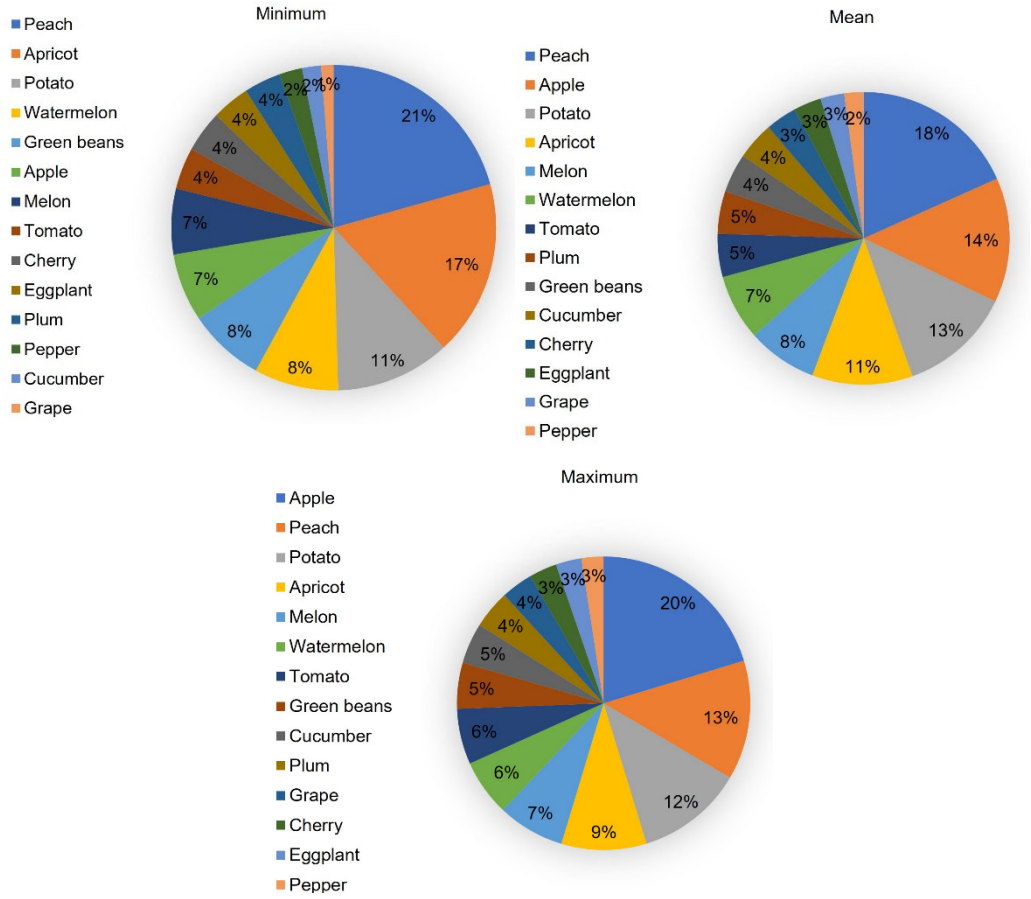


Figure 1. Contribution of ∑DI of nitrates based on the portion of fruits and vegetables consumption data.

As shown in Fig. 1, fruits and vegetables-the contributors of mean ∑DI of nitrates to Armenia's adult population–are arranged as follows: peach>apple>potato>apricot> melon>watermelon>tomato>plum>green beans>cucumber>cherry>eggplant>grape> pepper. Of all the examined fruits, the major contributors of ∑DI of nitrates are peaches (18%), apples (14%), and apricots (11%), and of vegetables–potato (13%). The minimal values of ∑DI are identical for the first three species, but different for the rest of them: peach>apricot>potato>watermelon>green beans> apple> melon> tomato > cherry> eggplant>plum>pepper>cucumber>grape. Relative to the maximal values of ∑DI of nitrates, the contribution is almost identical to mean values: apple>peach>potato>

apricot>melon>watermelon>tomato>green beans> cucumber >plum > grape >cherry> eggplant>pepper. In this case the major contributor of ∑DI of nitrates is apple (20%) followed by peach (13%) and potato (12%).

To more accurately estimate the health risks of nitrate intake via the examined fruits and vegetables, the Monte Carlo simulation for POE of ADI (3.7 mg kg^{-1} bw day^{-1}) was performed, clarifying the uncertainties and variability that cannot be provided by deterministic estimates alone (Fig. 2). Recent probabilistic assessments of contaminants in commonly consumed vegetables have similarly shown that contaminant concentration, food consumption rate, and body weight are influential determinants of estimated dietary health risks, highlighting the value of incorporating sensitivity analysis alongside Monte Carlo simulation (Armand et al., 2026).

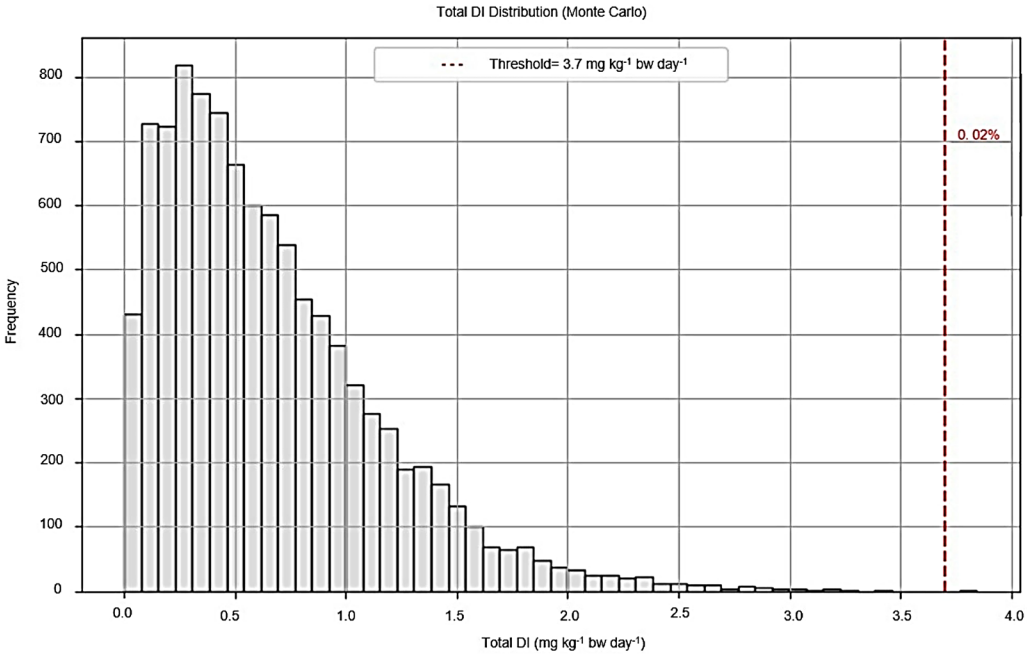


Figure 2. The probability of exceedance of the DI of nitrates as compared with the ADI of nitrates 3.7 mg kg^{-1} bw day^{-1}

In the original simulation, the probability of nitrate intake exceeding the ADI was 0.02% (Fig. 2), subject to the assumptions and limitations of the probabilistic model. In the 100,000-iteration verification run, no simulated values exceeded the ADI. Because of the very low frequency of this event, the exceedance estimate should be interpreted cautiously. The simulated exposure distribution was characterized by P50, P95, and P99 values of 0.56, 1.75, and 2.29, respectively.

Data on the daily intake of nitrates obtained worldwide are rather different from those derived in the frames of this research. For instance, Iranian researchers (Ghaffari et al., 2019) have established that, as a result of probabilistic data analysis 6.53% of daily intakes of nitrates were found to exceed the ADI set by EFSA. In low-risk areas, the share of total nitrate intake belongs to lettuce, followed by apple, onion, eggplant, cooked and raw vegetables, and tomato in high-risk areas, the highest nitrate intake is via onions,

followed by cooked vegetables, raw vegetables, apple, cucumber, and lettuce (Ghaffari et al., 2019). As compared with our research data, the major contributors of nitrates in this Iranian research are fruits, and the highest mean percentage of nitrate intake is associated with peach. In Austrian research (Vlachou et al., 2020), under all implemented scenarios, the probabilistic daily nitrate intake exceeds the ADI by 46.9 to 107%, and in all cases, the risk of nitrates is associated with vegetables. Different studies suggest that the major contributors of dietary nitrates are rather leafy vegetables than fruits (Cheng et al., 2021; Ghaffari et al., 2019; Vlachou et al., 2020; Wikoff et al., 2018). In our previous research, it was clearly shown that 47% and 55% of 24H recall survey respondents consume fruits and vegetables, respectively (Pipoyan et al., 2026). It should be mentioned that in Armenia's dietary patterns, leafy vegetables are not considered the majority of vegetable consumers. Meanwhile, 31% of the study population consumed potatoes in various ways (peeled, not peeled, boiled, fried, etc.) (Pipoyan et al., 2026). Our research does not cover leafy vegetables, and the major contributors of dietary nitrates to consumers on an individual basis are fruits, because the consumption rate and nitrate concentrations of fruits are far higher than those of vegetables.

Study limitations

This study has some limitations. The exposure assessment covered only commonly consumed fruits and vegetables. Limitations of the study include reliance on a single individual dietary survey, which may not fully reflect habitual long-term intake, and the aggregation of fruits and vegetables without item–specific differentiation of nitrate concentrations. The consumption data refer to Armenia's adult population (18–80+ years old) only; neither infants nor children are included. Other possible sources of dietary nitrates, such as water, meat products (sausages), and pretreated food were not included in this study. Seasonal differences, both in the consumption habits of fruits and vegetables were not included either. This can be significant in the detection of nitrates concentrations in food as rinsing, peeling or blanching, boiling or freezing can decrease their levels.

CONCLUSION

This research was implemented to assess nitrates exposure of Armenia's adult population through consumption of the most commonly consumed fruits and vegetables, was implemented based on data obtained from two scenarios: 1) the national household consumption data and 2) the individual consumption survey data. Conclusions derived from this research are as follows. First of all, as indicated by the results of data analysis of these two different surveys, there is a substantial difference between the adult's consumption rates of fruits and vegetables. Second, under the first scenario, the major contributors of dietary nitrates to Armenia's adult population are apples, under the second scenario-peaches. Third, in the case of vegetables, under both scenarios, the major contributor of dietary nitrates is the potato. Fourth, according to deterministic assessment data, under the Household scenario, there has been no exceedance of international ADI values. The health risks were insufficient as calculated HQ, and the HI in both scenarios was lower than the threshold value of one. And fifth, according to probabilistic (POE) assessment data, nitrate intake shows 0.02% of ADIs. The results of this research simulated the probability of exposure to nitrates via the consumption of

fruits and vegetables by adult consumers. This research is the first comparative study into dietary nitrate intake by the adult population of Armenia. It gives valuable insight into nitrate concentrations, intakes, and exposure based on deterministic and probabilistic approaches. Hence, its results will be very helpful for dietary risk assessors both in Armenia and region-wide. Also, the data of this particular research emphasize the probability of exposure through nitrate intake whenever not all nitrate sources (soil, water, meat products, leafy vegetables) are taken into consideration. Based on the limited range of foods analyzed, nitrate exposure appears low; however, this does not represent total dietary exposure. Therefore, with due regard to the limitations of this study, follow-up studies should include other nitrate intake sources, too, for more detailed nitrate exposure assessments by a BRAFO framework. The research findings will help authorities to improve and implement monitoring programs on nitrates in foods in Armenia.

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DECLARATION OF AI USE. The authors declare that artificial intelligence (AI) tools were used in the preparation of this manuscript. AI–assisted technologies: Grammarly software v1.2.289.1946 was utilized for language editing/grammar refinement. All the structural organization, statistical data treatment, and data interpretation were done by the authors. The authors take full responsibility for the accuracy, integrity, and originality of the final manuscript. No AI tools were used to generate data, fabricate references, or replace scholarly analysis.

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