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CONSUMPTION DIETARY SOURCES OF LYCOPENE, LUTEIN, AND ZEAXANTHIN AMONG YOUNG ADULTS LIVING IN MOSCOW

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ABSTRACT

Carotenoids are natural antioxidants, affecting apoptosis, absorbing active forms of oxygen, and improving visual performance through their blue light filtering capabilities. Lutein and zeaxanthin are carotenoids of the macular pigment that play a significant role in protecting against age-related macular degeneration (AMD), cataracts, and diabetic retinopathy. We analyzed the dietary sources of lycopene, lutein, and zeaxanthin of young adults living in a megapolis. We analyzed 431 food frequency questionnaires and used two different criteria for comparison: age (groups A1 and A2) and season (groups S1, spring, and S2, autumn). Raw red tomatoes and eggs are the main sources of carotenoids for the majority of respondents regardless of age and season. Significant differences between age groups were found for parsley, carrot, cheeseburger, and spring onion. Foods with high levels of carotenoids (tomato juice, pumpkin, spinach, and sprouts) were absent in the diets of most of the study participants. Watermelons and persimmons are seasonal sources of lycopene, lutein, and zeaxanthin. Dietary sources of carotenoids are present in insufficient quantities in the diets. Foods with high levels of lycopene, lutein, and zeaxanthin are absent or only occasionally included in the diet.

Keywords: lycopene; lutein; zeaxanthin; dietary source; diet

INTRODUCTION

Carotenoids are the most common natural pigments. Lycopene, lutein, and zeaxanthin are tetra-terpenoid (and their derivatives) having eight isoprene units in their 40-carbon skeleton **(Britton, 1983)**. Carotenoids comprise two classes: carotenes (β-carotene, lycopene) and xanthophylls (lutein, zeaxanthin, and meso-zeaxanthin). Lycopene and xanthophylls cannot be converted into vitamin A and are called non-provitamin A carotenoids. These carotenoids form the macular pigment, the concentration of which peaks in the foveola. Meso-zeaxanthin is at the epicenter of the macula, zeaxanthin is in the mid-peripheral macula, and lutein is in the peripheral macula **(Lima, Rosen and Farah, 2016)**. Using resonance Raman spectroscopy, carotenoids species can be detected, quantified, and distinguished **(Arteni et al., 2015)**. Carotenoids are natural lipid-soluble antioxidants that quench oxygen free radicals and improve visual performance by filtering blue light. Lycopene affects apoptosis, growth factors, and expression of xenobiotic-metabolizing enzymes **(Dadali, Tutel'yan and Dadali, 2011)**.

Epidemiologic studies have revealed an inverse relationship between the risk of incidence and progression of age-related macular degeneration or cataract and xanthophyll levels in the diet **(Moeller, Jacques and Blumberg, 2000)**. The consumption of dietary sources of lutein, zeaxanthin, and meso-zeaxanthin increases macular pigment optical density, improves contrast sensitivity and visual function and prevents progression of diabetic retinopathy in patients with non-insulin-dependent type 2 diabetes **(Moschos et al., 2017)**.

Carotenoids obtained from food sources accumulate and modify in humans and animals. The possibility of biosynthesis of carotenoids in the human body is not currently proven. Lutein and zeaxanthin are found in relatively high levels in green leafy vegetables (kale, lettuce, broccoli, peas, and spinach), corn, and egg yolks **(Abdel-Aal et al., 2013)**. In addition, zeaxanthin is present in certain yellow or orange fruits and vegetables, for example, nectarines, oranges, papaya, and orange pepper. Carotenoids are found in guava (lutein) and lychee (zeaxanthin) **(Mozaffarieh, Sacu and Wedrich, 2003)**. Lycopene is found in red tomatoes and tomato-containing products (ketchup, tomato juice, tomato paste, pizza, and lasagna), watermelon, pink and red grapefruits, papaya, and persimmon **(USDA, 2018)**. Studies have shown that plasma lutein and zeaxanthin concentrations increase with the daily consumption of fruits and vegetables. Therefore, concentrations of lutein and zeaxanthin in plasma can be used as biomarkers of fruit and vegetable consumption. No positive relationship exists between plasma lycopene concentration and mixed fruits and vegetable intake. Thus, the concentration of lycopene in the plasma is the most

suitable biomarker of tomato (whole and processed) consumption **(Couillard et al., 2016)**.

The main carrier of lutein and zeaxanthin in the bloodstream is high-density lipoprotein. Lycopene is preferentially carried by low-density lipoprotein **(Mozaffarieh, Sacu and Wedrich, 2003)**. The bioavailability of carotenoids from food sources is associated with nutrient-rich sources, methods of preparation, and the presence of fats in the diet. The bioavailability of lutein and zeaxanthin from plant sources is low because these carotenoids are localized in the chloroplasts and chromoplasts of plants. Dietary fiber from plant sources reduces carotenoid absorption in the intestine. The bioavailability of lutein and zeaxanthin from egg yolks is higher than from vegetables due to the presence of fats **(Eisenhauer et al., 2017)**. Thermal and mechanical treatment of tomatoes increases the bioavailability of lycopene. The concentration of lycopene in plasma after consumption of tomato paste is much higher than after the intake of a similar amount of lycopene with fresh tomatoes **(Gärtner, Stahl and Sies, 1997)**. The official recommended daily carotenoid intake in Russia is 5 mg per day for lycopene and 6 mg per day for lutein and zeaxanthin (in total) **(Recommended consumption levels of food and biologically active substances, 2004)**. A study showed that 6 mg of lutein and zeaxanthin per day took with the diet reduces the risk of age-related degeneration **(Seddon et al., 1994)**. The use of enriched products, mainly wheat and milk products, is positively evaluated in ensuring daily recommended levels of lutein and zeaxanthin are consumed. The percentage of absorption of lutein and zeaxanthin does not depend on the dose of the consumed product, but increases depending on the content of carotenoids in the enriched product **(Granado-Lorencio et al., 2010)**. In this study, we analyzed the frequency of consumption and dietary sources of lycopene, lutein, and zeaxanthin in the diets of young adults living in a megapolis.

Scientific hypothesis

There is no relationship between the age of the students, the season of the survey**,** and the leading sources of non-vitamin carotenoids.

MATERIAL AND METHODOLOGY

Samples

Our sample consisted of students from Federal State Autonomous Educational Institution of Higher Education I.M. Sechenov First Moscow State Medical University of the Ministry of Healthcare of the Russian Federation (Sechenov University). The structure of the respondents was:

- Total number of respondents: 431
- Man: 72.4%
- Woman: 27.6%

The age categories:

- 18.49 ±0.94: 55.7% (group A1)
- 23.42 ±1.35: 44.3% (group A2)

The season categories:

- spring (March and April): 50.5% (group S1)
- fall (September and October): 49.5% (group S2)

Description of the Experiment

Questionnaire preparation

We used a food frequency questionnaire to assess dietary intake. The food frequency questionnaire contained 35 foods, including food sources of lycopene (tomato paste, pink and red grapefruit, and juice from them, and watermelon), lutein, and zeaxanthin (green peas, zucchini, corn, pumpkin, sprouts, spring onion, pistachios, spinach, parsley, basil, celery, egg yolks, carrot, blackberry, blueberry, and kiwi). The questionnaire included food sources with different levels of carotenoids: raw red tomatoes, tomato-containing products (pizza, lasagna, pasta, sandwiches from fast-food restaurants, hamburgers, cheeseburgers, sauces, and tomato juice), and persimmon **(USDA, 2018)**. The questionnaire considered the methods of food preparation: fresh consumption, pickling and salting, cooking, frying, and preservation. The questionnaire also included the frequency of consumption of carotenoids food sources: weekly, monthly (1 – 5 times per month), episodic consumption (once in 2 – 3 months), and absence in the diet. The weekly consumption was separated into several groups: 6 – 7, 3 – 5, and 1 – 2 times per week. The volume of one-time consumption was determined for every frequency group. The food frequency questionnaire included anthropometric data of respondents (height, body weight); their age and sex; data on additional intake of vitamin complexes containing lycopene, lutein, and zeaxanthin; and the presence of diseases of the organs of vision (glaucoma, myopia, etc.). All questions were mandatory.

Conducting a questionnaire survey:

A questionnaire survey was conducted at Sechenov University. Data collection was anonymous. Each participant could complete the questionnaire only once. The survey took place in the period: March – April 2019 and September – October 2019.

Number of questionnaires:

The total number of processed questionnaires was 143. A total of 19 questionnaires were rejected due to incorrect data: age and body weight were not specified and/or the frequency of inclusion in the diet and/or one-time consumption was not determined.

Creating a dataset:

We prepared the final data set for further processing in Microsoft Excell (Office 365). The structure of the dataset was adapted to further statistical processing.

Processing the answers:

We evaluated all questions and visualized the respondents' answers by figures.

Statistical Analysis

We used Fisher's angular transformation criterion (φ) to determine the validity of differences between comparison groups. At $\varphi \leq 1.64$, the values are in the zone of statistical insignificance. Statistical significance was indicated according to the criterion $p < 0.05$. Statistical processing was performed in Microsoft Excel 365 in combination with XLSTAT (version 2019.3.2).

RESULTS AND DISCUSSION

The weekly diet of more than half of the respondents (groups A1 and A2) contained sources of lycopene, lutein, and zeaxanthin. Around 30% of the students, in their weekly diet, included lettuce, ketchup, parsley, and orange juice. Significant differences between the comparison groups were found for parsley, carrot, cheeseburger, and spring onion (Table.1).

The frequency of the inclusion of non-vitamin carotenoids sources in the weekly diet varied: raw red tomatoes (14.10%), lettuce (8.97%), orange juice (7.69%), and eggs (6.41%) were consumed 6 – 7 times per week in group A1. In group A2, the same frequency is typical for red raw tomatoes (11.29%), parsley (9.68%), spring onion, and eggs (8.06% each). For the majority of respondents, regardless of age, the main source of lutein and zeaxanthin was eggs; the main source of lycopene was raw red tomatoes (Figure 1). With a frequency of consumption of one to five times a month in the diet, more than one-third of the respondents identified other sources of non-vitamin carotenoids. There was a smaller variety of sources of lutein and zeaxanthin and almost no lycopene sources in group A1 compared to group A2 (Table 2).

There were no reports of the consumption of foods with high levels of carotenoids in the diet of the majority of respondents in either group: spinach (75.7% in A1, 53.2% in A2); pumpkin (74.4% and 59.7%); sprouts (64.1% and 56.5%); celery (65.4% and 51.6%); basil (60.3% and 54.8%); fast food products with tomato" lasagna, hamburgers, sandwiches, paste (69.2% and 75.8%); and squashes including squash puree (55.1% and 56.5%, respectively). There are no spring onion (64.1%) or tomato juice (55.1%) reported in the diet of the majority of respondents in group A1. The frequency of consumption of these sources for respondents of group A2 was 38.75% for tomato juice and 16.3% for spring onion. Other products listed in the questionnaire were reported in the diet occasionally and in insufficient quantities. We found significant differences between red and pink grapefruit and canned red tomatoes (Table 3).

In the weekly diet in spring and fall, the main source of lycopene in the majority of students was red raw tomatoes; the main source of lutein and zeaxanthin was eggs (Figure 2). We found significant differences concerning parsley and eggs. These sources were present in the weekly diet in the spring, and we found no significant differences in the sources of non-vitamin carotenoids consumed 6 – 7 times per week between group S1 and group S2 students (Table 4).

Consumption of seasonal sources of lycopene (watermelon) and lutein and zeaxanthin (persimmon) corresponds to seasonality. In group S2 students, weekly consumption of watermelon was 10.4% and that of persimmon was 11.8%. Group S1 students reported no watermelon (100%) or persimmon (94.6%) in their weekly diet. The daily diet of students in groups S1 and S2 contained food sources with high levels of lycopene (red raw tomatoes) and sources with good bioavailability of lutein and zeaxanthin (eggs). The daily consumption of these foods does not ensure the intake of non-vitamin carotenoids at the recommended levels. Students of neither group included products with high levels of studied carotenoids in the diet that were presented in the questionnaire, among which were sources of lycopene: tomato juice (49.7% S1, 54.9% S2), pink and red grapefruit juice (49.0% and 58.3%), canned vegetables in tomato sauce (77.6% and 48.6%), fast food products with tomato (77.6% and 78.5%, respectively); and sources of lutein and zeaxanthin: pumpkin (68.0% S1, 72.2% S2), sprouts (64.6% and 73.6%), celery (64.0% and 72.2%), spinach (61.9% and 79.9%), blackberry (42.9% and 66.7%), and blueberry (48.3% and 70.8%, respectively). Among all respondents (431 students), 48.03% reported the presence of myopia, and 1.16%, the presence of retinopathy. The additional intake of vitamin complexes was at 6.03% of respondents, but only 1.62% took complexes containing lycopene or lutein and zeaxanthin.

Our results confirmed the data obtained in Spain: The major sources of lycopene are raw red tomatoes, dishes with tomato products and watermelon **(Estévez-Santiago, Beltrán-de-Miguel and Olmedilla-Alonso, 2016)**. These findings do not contradict the results of a study in Belgium, according to which the leading sources of lycopene were tomatoes, foods containing tomatoes and tomato sauces in ready-to-eat meals **(Vandevijvere et al., 2014)**. In accordance with the results of research conducted among the population of South Korea, the study found that there are insufficient quantities of these major sources of lycopene in people's diets **(Park, Kim and Shin, 2020)**. In Brazil, about 55% of people's daily intake of lycopene is due to the inclusion of vegetables (tomatoes and red lettuce) in their diet, and 45% is due to the inclusion of fruits (watermelon and papaya) **(Vargas-Murga et al., 2016)**.

Authors of scientific works **(Fukushima et al., 2021; Van Hoang et al., 2018)** have reported that in Japan and Vietnam, products that contain tomatoes are the main contributors to the consumption of lycopene in people's diets. These findings do not contradict the meta-analysis, according to which tomatoes, tomato sauces, ketchup, watermelon, pink grapefruit and rose hips are the main sources of lycopene **(Dias et al., 2021; Meléndez-Martínez et al., 2021)**.

According to **Böhm et al. (2021)**, consumption of tomato juice, products containing tomato sauce (such as pizza) and ketchup significantly increase levels of lycopene. Products containing tomatoes are also a major source of lycopene among the Polish population (50% of the incoming level came from processed tomatoes and 32% from fresh tomatoes) **(Hamułka, Wawrzyniak and Sulich, 2012)**. Tomatoes and bolognaise sauce were the major sources of lycopene in Australia **(Manzi et al., 2002)**. This confirms the data provided by **Stuetz et al. (2016)**, which indicated that the populations of Italy, Belgium, and Greece had high levels of lycopene intake from fruits and vegetables, as well as from the consumption of French fries with various tomato sauces and ketchup. In their assessment of seasonal intake, higher levels of lycopene were recorded in the summer and fall seasons.

Table 1 Sources of non-vitamin carotenoids in the weekly diet.

Food Sources	Group A1 %	Group A2 %	φ
Egg	62.82	70.96	1.023
Raw red tomato	74.36	62.90	1.469
Lettuce	44.86	45.17	0.059
Ketchup and tomato sauces	43.59	37.09	0.764
Parsley	35.90	50.01	1.645*
Orange juice	38.46	25.81	1.587
Basil	25.64	24.19	0.176
Celery	24.36	25.81	0.176
Broccoli (boiled)	23.08	20.97	0.294
Raw carrot	20.50	38.71	2.351*
Cheeseburger	21.80	6.45	3.526*
Spring onion	5.13	35.48	4.819*

Note: * p <0.05.

Table 2 Sources of non-vitamin carotenoids in the monthly diet.

Group A1	Group A2
Carrot, pizza, canned green peas, canned corn, orange juice	Canned green peas in dishes, canned corn in dishes, carrot, pizza, orange juice, squash puree, kiwi, grapefruit red and pink, raw red tomato, broccoli, spring onion

Table 3 Sources of non-vitamin carotenoids included occasionally in the diet.

Food Sources	Group A1 %	Group A2 %	φ
Watermelon	79.49	72.58	0.952
Blueberry	53.85	45.16	1.023
Blackberry	44.87	58.06	1.557
Kiwi	44.87	37.1	0.934
Canned red tomatoes	43.59	58.06	1.716*
Pistachios	43.58	54.84	1.322
Persimmon	37.18	37.10	0.012
Red and pink grapefruit	46.16	30.65	1.887*

Note: * p <0.05.

Table 4 Sources of non-vitamin carotenoids in the weekly diet, and consumed 6 – 7 times a week.

Food Sources	Group S1 % weekly diet/ 6 – 7 times per week	Group S1 % weekly diet/ 6 – 7 times per week	φ
Eggs	75.51/8.16	56.95/10.42	3.369*/0.648
Red raw tomatoes	69.39/10.88	72.22/16.67	0.529/1.441
Ketchup	40.14/2.72	34.42/3.47	0.997/0.392
Parsley	44.89/7.48	33.33/4.17	2.038*/1.211
Lettuce	40.82/3.40	31.95/4.17	1.560/0.358
Spring onion	34.01/6.80	31.25/4.86	0.495/0.699
Carrot	32.66/3.40	24.31/4.17	1.586/0.358
Orange juice	28.57/2.04	22.92/1.39	1.117/0.400
Eggs	75.51/8.16	56.95/10.42	3.369*/0.648
Red raw tomatoes	69.39/10.88	72.22/16.67	0.529/1.441
Ketchup	40.14/2.72	34.42/3.47	0.997/0.392
Parsley	44.89/7.48	33.33/4.17	2.038*/1.211
Lettuce	40.82/3.40	31.95/4.17	1.560/0.358

Note: * p <0.05.

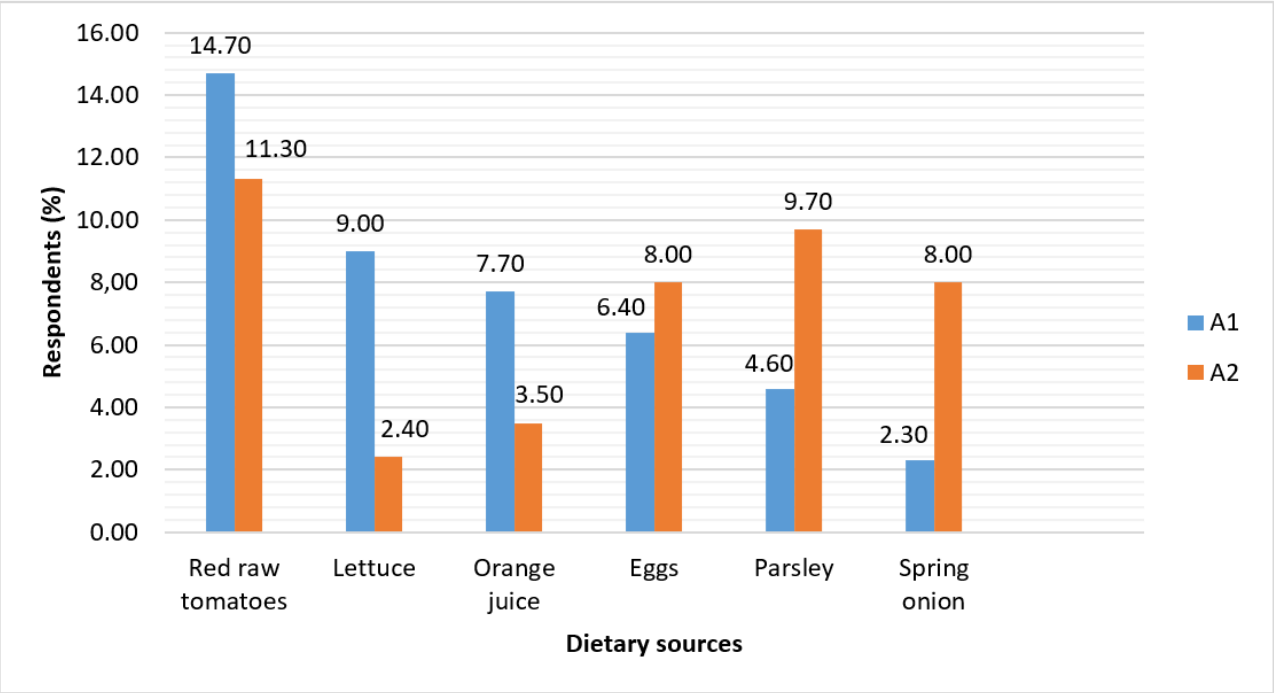

Figure 1 Dietary sources of non-vitamin carotenoids in daily diet.

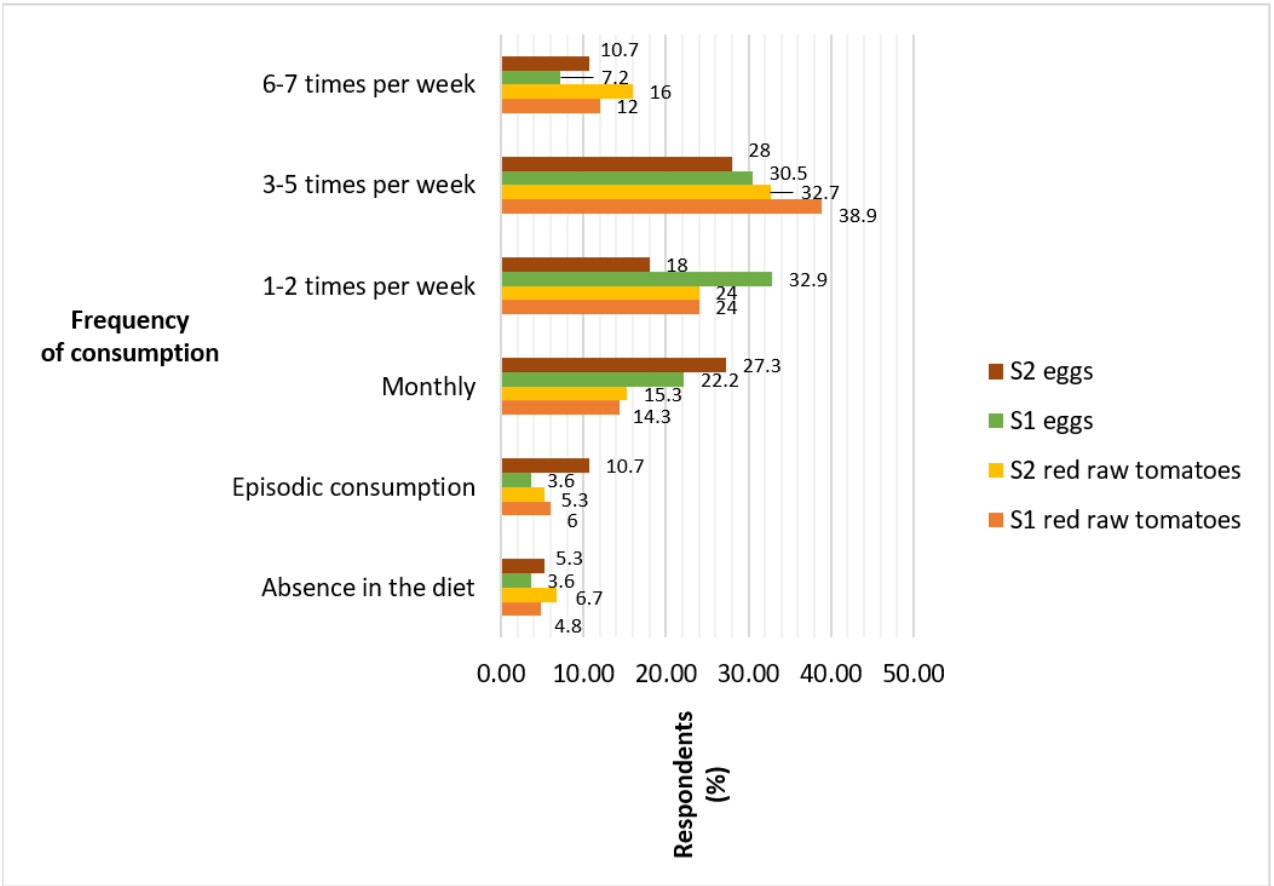

Figure 2 The frequency of the inclusion of red raw tomatoes and eggs in the diet.

Raw tomatoes are the major source of lycopene for the respondents from Germany, regardless of age (the majority of respondents, regardless of gender and age, include them in their weekly and monthly diets), as well as tomato sauces and ketchup (most of the respondents include them in their diet two to three times per month) **(Weber et al., 2020)**. **Andarwulan et al. (2021)** also declared that rural Indonesians have a higher lycopene intake than urban residents. This is due to their more frequent consumption of vegetables and fruits. In the Hungarian population, the major sources of lycopene were found to be raw red tomatoes, sauces, ketchup, barbecue sauce, and instant foods containing tomato powder **(Lugasi et al., 2003)**.

Fast food products containing tomatoes provide different contributions to the total intake of lycopene in different countries. A five-country comparative study showed that the main source of lycopene in all countries studied, except the Republic of Ireland, was raw red tomatoes. In France, the U.K., and the Republic of Ireland, the main sources of lycopene were canned tomatoes and pizza. In the Netherlands, sources of lycopene included tomato soup and pizza; in Spain, the main source was tomato puree **(O'Neill et al., 2001)**. The data obtained in these studies agree with the results of our study and confirm that the main sources of lycopene are raw red tomatoes and sauces containing tomatoes.

Food sources of lycopene differed among ethnic groups. The major source of lycopene was cooked tomato products for Hispanics and pasta dishes for non-Hispanic whites **(Bermudez et al., 2005)**. According to **Zhou et al. (2016)**, pizza and pasta were the major sources of dietary lycopene among predominantly low-income middle-aged and older Blacks and Whites living in the southeastern U.S. **Mažeikienė et al. (2016)** also declared that in Lithuania, the major sources of lycopene were tomatoes and tomato products (78.8%), watermelons (11.9%), and pink grapefruits (9.3%). Ethnolinguistic region has a statistically significant impact on the lycopene intake in the Lithuanian population.

Authors of scientific works **(Sulich, Hamulka and Nogal 2015; Hamułka, Wawrzyniak and Sulich, 2012)** reported that the main contributors to the intake of lutein are fresh and cooked vegetables, including green leafy vegetables. **Manzi et al. (2002)** also declared that for people in Australia who is over the age of 55, the major sources of lutein and zeaxanthin were green peas, broccoli, and oranges. Meanwhile, the results of a University of Panama study reported that raw tomatoes, egg yolks, and corn tortillas were the main contributors to the intake of lutein and zeaxanthin in the daily diets of the majority of respondents **(Alvarado-Ramos et al., 2018)**.

There are differences in the dietary sources of xanthophylls, according to a survey in five European countries (U.K., Ireland, Spain, France, and the Netherlands). The highest levels of daily intake of lutein and zeaxanthin were found to be from lettuce and spinach in Spain and France; in the Netherlands, the average daily intake of lutein and zeaxanthin was achieved through the consumption of spinach and broccoli. The lowest intakes of lutein and zeaxanthin were found in the U.K. and Ireland, respectively. In these countries, the main sources were broccoli and green peas **(O'Neill et al., 2001)**. Additionally, according to a U.K. study, green lettuce, peas, broccoli, watercress, and spinach are potentially major sources of lutein, along with carrots, cucumber, beans, and Brussels sprouts **(Scott et al., 1996)**. Though watercress and spinach are very good sources of lutein, a relatively low percentage of the respondents consumed them.

According to a study in Japan, the best sources of lutein and zeaxanthin are spinach, cucumber, egg, spring onion, and Chinese onion **(Fukushima et al., 2021)**. **Vargas-Murga et al. (2016)** and **Carnauba et al. (2021)** conducted studies that show that in Brazil, the main sources of lutein are pumpkin, kale, and green leafy vegetables, and the main sources of zeaxanthin are orange, corn, and mango. Meanwhile, a research study in Spain found that lutein and zeaxanthin obtained from fruits (not from green leafy vegetables and egg yolks) play an important role in the prevention of age-related macular degeneration **(Estévez-Santiago, Beltrán-de-Miguel and Olmedilla-Alonso, 2016)**. According to **Durec et al. (2019)**, almost a third of respondents from Slovakia eat fruit one to three times a week, 26% of respondents consume fruit once a day, 23% from time to time and 20% several times a day. At the same time, the majority of respondents prefer to eat fresh fruit.

According to **Langhansova et al. (2021)**, European ferns can contribute to the human diet as a rich source of lutein. Thus, we found differences among the sources of lutein and zeaxanthin. In Russia (particularly in Moscow), the main source of lutein and zeaxanthin was eggs only.

CONCLUSION

Regardless of the age of the students and the season of the survey, red raw tomatoes and ketchup (for lycopene), and eggs (for lutein and zeaxanthin) were the leading sources of non-vitamin carotenoids. These food sources were present in the daily diet of less than 15% of students living in the megapolis. There were no additional reported food sources of lycopene (red and pink grapefruits, and watermelon), lutein, or zeaxanthin (green leafy vegetables, pumpkin, sprouts, corn, spring onion, and squashes) in the diets of most respondents. Seasonal differences in the consumption of watermelon and persimmon did not significantly contribute to the total level of carotenoids because the inclusion of these products in the diet was noted in only 10.4 – 11.8% of respondents. This is the first study to examine the consumption dietary sources of non-vitamin carotenoids among young adults living in the megapolis. The next step of our research will analyze the content of lycopene, lutein, and zeaxanthin in their diet.

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The authors declare no conflict of interest.

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All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of IM Sechenov First Moscow State Medical University (Sechenov University) (protocol #03-20, dated February 19, 2020).

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