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Assessment of vitamin- and mineral-content stability of tomato fruits as a potential raw material to produce functional food

Zharkova Irina[1*], Pochitskaya Irina[2], Efremov Dmitriy[1], Plotnikova Inessa[1], Chusova Alla[1], Pronkina Alena[1], Harutyunyan Natalya[3]

[1]Voronezh State University of Engineering Technologies, Voronezh, 394036, Russian Federation; [2]RUE "Scientific and Practical Center for Foodstuffs of the National Academy of Sciences of Belarus", 29, Kozlov Str., Minsk, 220037, Republic of Belarus; [3]Armenian National Agrarian University, 74 Teryan St, Yerevan 0009, Armenia.

***Corresponding Author**: Irina Zharkova, DSc in Technology, Associate Professor, Department of Bakery, Confectionery, Pasta and Grain Processing Technologies, Voronezh State University of Engineering Technologies, Voronezh, Russian Federation

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ABSTRACT

Background: Tomatoes are a valuable source of biologically active substances (vitamin C, lycopene, lutein, macro- and microelements) and can be used to produce functional foods.

Objective: Nine varieties of tomato fruits, featuring a spectrum of colors such as red, yellow, and dark hues (brown, burgundy), were examined. These tomatoes were cultivated in open ground in both the Russian Federation and the Republic of Belarus**.**

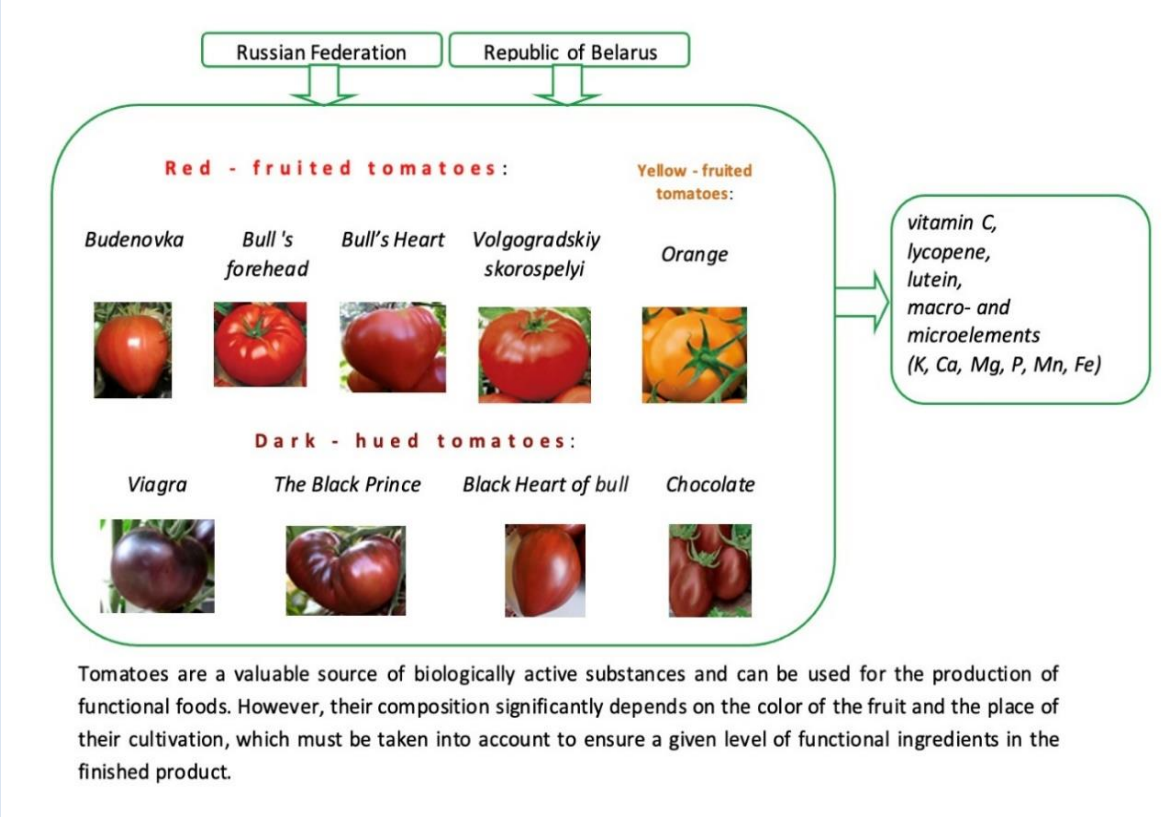
Methods: The mineral composition of tomato fruit samples was determined using an atomic emission spectrometer with inductively coupled plasma, mass fractions of vitamin C and carotenoids were determined by high-performance liquid chromatography.

Results: The highest vitamin C content was observed in the fruits of tomato varieties Viagra and Chocolate, cultivated in the villages of Khokhol and Nikonovo in the Voronezh Region, Russia, and in the variety Budenovka, grown in Nikonovo. Additionally, the highest lycopene content was identified in the fruits of The Black Prince, cultivated in the agro-town Samokhvalovichi, Belarus; Volgogradskiy skorospelyi, grown in Nikonovo; Bull's Heart, cultivated in Khokhol in the

Voronezh Region, Russia; and Black Heart of Bull, cultivated in Khokhol and Nikonovo respectively. Notably, tomatoes of the varieties The Black Prince (agro-town Samokhvalovichi, Belarus), Chocolate, Black Heart of Bull, and Bull's Heart (Khokhol, Russia) exhibited a significant amount of lutein. Furthermore, tomatoes of the variety Budenovka, grown in Khokhol, Russia, displayed high mineral saturation. Varieties Bull's Heart and Black Heart of Bull, grown in the same region, were found to be rich in macro- and trace elements (K, Ca, Mg, P, Mn, Fe). The optimal calcium-to-phosphorus ratio (1:1.5) was observed in varieties Bull's Forehead, Black Heart of Bull, and Budenovka, while the optimal calcium-to-magnesium ratio (1:0.7) was present in the fruits of tomato varieties Volgogradskiy skorospelyi, Bull's Forehead, Budenovka, Black Heart of Bull, Bull's Heart, and Orange, grown in various regions of the Russian Federation.

Conclusion: The inclusion of biologically active substances, notably lycopene, lutein, Vitamin C, and essential minerals (Potassium, Calcium, Magnesium, Phosphorus), positions tomatoes as valuable sources for developing functional foods and those designed to prevent cardiovascular diseases. The composition of tomatoes varies significantly based on the fruit's color and the cultivation location. This variability underscores the importance of considering these factors to achieve the desired level of functional ingredients in the final product.

Keywords: tomato fruits, biologically active substances, vitamin C, lycopene, lutein, macro- and microelements.



Tomatoes are a valuable source of biologically active substances and can be used for the production of functional foods. However, their composition significantly depends on the color of the fruit and the place of their cultivation, which must be taken into account to ensure a given level of functional ingredients in the finished product.

INTRODUCTION

Notwithstanding the absence of universally accepted vision of interpretation of the term "functional food", all researchers agree upon the opinion that specific biological effects, which are inherent to those products, are conditioned by the presence of biologically active products in them, as well as vitamins, vitamin analogs, antioxidants, etc. [1-3]. Microbiologically or chemically synthesized medicine, processed products of fruits, berries and vegetables, including tomatoes, can serve as sources for biologically active substances [4-9].

According to the Food and Agriculture Organization of the United Nations (FAO), tomato fruits have consistently held the top position in terms of growing volumes for the past two decades, from 2000 to 2021, constituting 16% of the total vegetable production. In 2021, the global volume of their production amounted to 189 million tons [10]. Tomatoes are consumed both fresh and processed (pasta, juice, puree, sauce, ketchup, whole dried or dried tomatoes, tomato powder), making up an important part of the diet of the population in almost all regions of the world [11-14]. The fruits of tomatoes deserve attention not only due to their taste and gastronomic advantages, but also owing to the presence of biologically significant substances, including vitamins and minerals [15-19]. Work is underway to create varieties of tomatoes rich in anthocyanins, such as "Sun Black" [20]. From the perspective of using tomato fruits and its processed products as a source of functional food ingredients, the presence of vitamin C, lycopene, lutein, potassium, calcium, magnesium, and phosphorus deserves special attention [5-6, 9, 21-23].

One of the first steps for developing functional foods is justifying the choice of raw materials from the standpoint of the presence of biologically active substances in them [24, 25]. The content of mineral substances in tomato fruits, as well as vitamins and other biologically active substances, largely depends on varietal characteristics and growing conditions [26]. In this regard, it is very relevant to research the accumulation of essential nutrients in tomato fruits, depending on the variety and region of cultivation. The main objective of the article is to research the content of biologically active substances in tomatoes of the nine varieties grown in the Russian Federation and in the Republic of Belarus.

MATERIALS AND METHODS

Materials: The objects of research were the fruits of red-fruited (varieties *Budenovka, Bull's forehead, Bull's Heart, Volgogradskiy skorospelyi)* yellow-fruited (*Orange*) and dark - hued (*Viagra, Black Heart of bull, The Black Prince, Chocolate*) tomatoes. They were grown outside in different soil and climatic conditions (in the agro-town of Samokhvalovichi, Minsk region of the Republic of Belarus; in the villages of Nikonovo Verkhnekhavsky district and Khokhol, Khokholsky district of the Voronezh region of the Russian Federation (Table 1)).

The originator of the tomato variety *Budenovka* is "Tomagros Breeding and Seed Company" LLC (Moscow, Russia); *Bull's forehead* – Dederko V. N. (Novosibirsk, Russia); *Bull's Heart* – "Agrofirm Poisk" LLC (Moscow region, Ramensky district, Vereya, Russia), "Center-Ogorodnik" LLC (Moscow region, Ramensky district, Vereya, Russia), "Gavrish Breeding Company" LLC (Moscow, Russia); *Viagra* – "Research Institute of Vegetable Breeding" LLC (Moscow, Russia), "Gavrish Breeding Company" LLC (Moscow, Russia); *Volgogradskiy skorospelyi* – "Volgogradsortsemovoshch" JSC (Volgograd, Russia), Popova L.N. (Volgograd, Russia), "Volgograd State Agrarian University" (Volgograd, Russia), "Gavrish Breeding Company" LLC (Moscow, Russia); *The Black Prince* – "Scientific and Production Corporation "NK LTD"" JSC (Moscow region, Shchyolkovo, Russia); *Chocolate* – "Agrofirm Sedek" LLC (Moscow region, Domodedovo, Russia); *Black Heart of bull* – "Agrofirm Aelita" LLC (Moscow, Russia); *Orange* - Republican Scientific and Production Unitary Enterprise "Institute of Vegetable Growing" (Minsk region, Minsk

district, ag. Samokhvalovichi, Republic of Belarus).

Tomatoes were grown using seedlings. The planting was implemented on March 1-5, 2022. The seedlings were transplanted into open ground on May 20-25, 2022. Harvesting was carried out gradually with the fruits ripening in July-August 2022. The analysis of chemical contents of tomato fruits was conducted in RUE "Scientific and Practical Center for Foodstuffs of the National Academy of Sciences of Belarus" 3-5 days after harvesting. For this purpose, the tomato samples were transported by motor vehicles from the cultivation sites to the laboratory.

The work was carried out according to the scheme presented in figure 1.

Table 1: Characteristics of tomatoes used in the work.

Name of the variety	Appearance of fruits	Characteristics of fruits
Red - fruited tomatoes:		
Budenovka		The fruit is heart-shaped, slightly ribbed, fleshy, red, weighing 150-350 g. The variety is medium-early.
Bull 's forehead		The fruits are bright red, fleshy, good taste. Large, dense, weighing 300-400 g (up to 600 g). The variety is medium-ripe.
Bull's Heart		The fruits are maroon-purple, heart-shaped, dark maroon on the cut, the skin is thin, easily removed from the pulp. Tomato pulp is dense, fleshy, the average weight is 400 g. The variety is medium-late.
Volgogradskiy skorospelyi		The fruits are bright red in color. The shape is rounded-flattened, sometimes smoothed edges are noticeable. Medium size, weight 80-100 g. Early ripening variety.
Yellow - fruited tomatoes:		
Orange		Unripe fruits are light green, mature fruits are bright orange, weighing around 80-120 g. Mid-early variety.
Dark - hued tomatoes:		
Viagra		Fruits in the stage of maturity are red-brown, thick-walled, dense, juicy. The shape is flat-rounded, weight 100-110 g. The variety is medium-ripe.
The Black Prince		The fruits have a dark red color: the upper part of the tomato is black and crimson, and the lower part is bright crimson. The inner part has an almost black color. Fruit weight 250-300 g (can reach 400 g). Medium - ripened variety.

Name of the variety	Appearance of fruits	Characteristics of fruits
Black Heart of bull		The fruits are deep brown, round-heart-shaped, weighing 300-750 g. The flesh is dark, sugary, low-seeded, juicy, and sweetly aromatic with pleasant fruity notes. Medium - ripened variety.
Chocolate		The color of the mature fruit is brown with green strokes, dense, smooth, grows in brushes. The fruits are small, 30-40 g. They taste very sweet. The variety is medium-ripe.

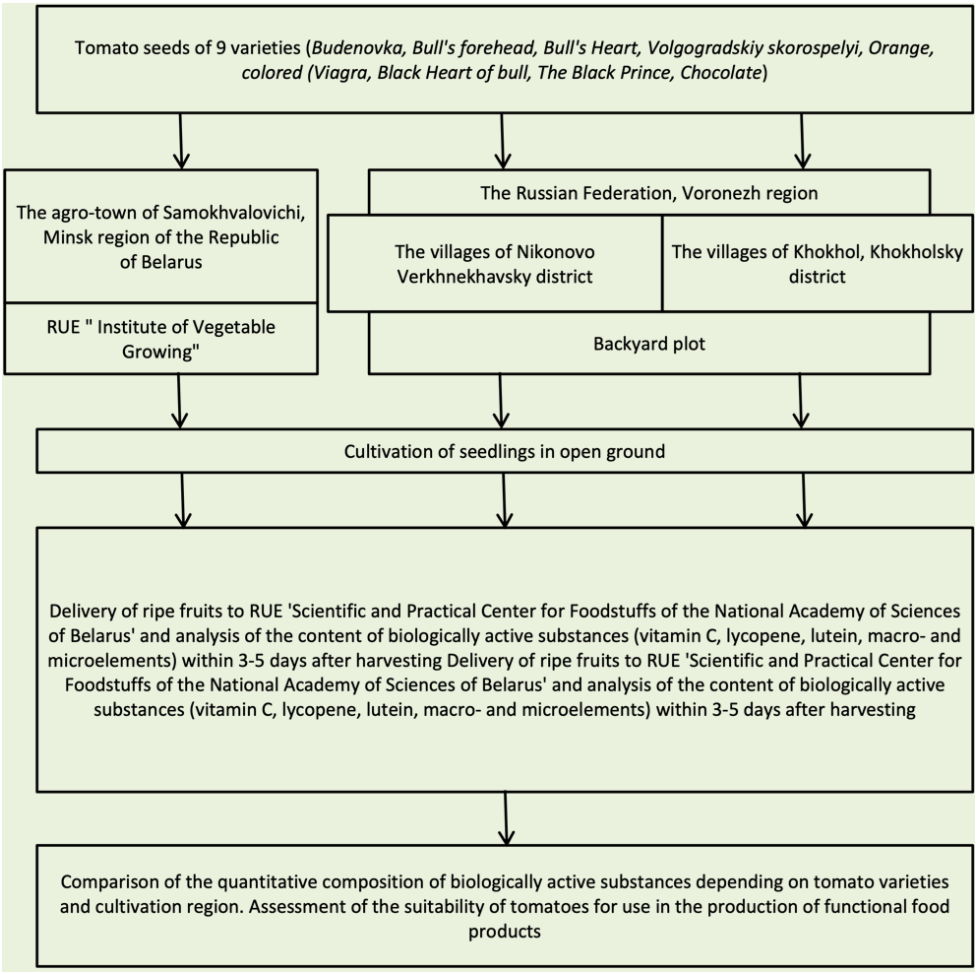


Figure 1. The scheme of experimental research

Methods: The mineral composition of tomato fruit samples was determined using an atomic emission spectrometer with inductively coupled plasma Optima 2100 DV [27]. The essence of the method lies on oxidative-acid, or so-called "wet" mineralization of the samples under investigation, followed by the analysis of essential chemical elements using the atomic emission spectrometry method by employing high-frequency inductively coupled argon plasma as an excitation source. The aim of sample preparation is to convert the sample into dissolved form, suitable for the use of spectrometer. The conversion into a solution is achieved by treating the

samples with concentrated nitric acid through open and autoclave decomposition. Utilizing the scheme of gradual scanning enables us to form the required list of essential spectral lines, corresponding to the detected elements. The intensity of spectral line of an element is specifically linked to its concentration in the sample, which allows to attain reliable calibration characteristics directly proportional to the interval of five to six orders of magnitude with the use of accompanying spectrometer software. The guaranteed detection limit is in the range of mcg/l.

For the detection of the mass fraction of vitamin C, the method of high-performance liquid chromatography was employed according to [28]. The method is based on the extraction of vitamin C from the sample with a solution of metaphosphoric acid, followed by the reduction of L (+)-dehydroascorbic acid to L (+)-ascorbic acid and by the determination of the total content of L(+)-ascorbic acid using high-performance liquid chromatography (HPLC) with spectrophotometric detection at a wavelength of 265 nm.

Mass fractions carotenoids (lycopene and lutein) were determined according to [29]. The method is based on the quantitative measurement of carotenoids using high-performance liquid chromatography with a reverse-phase mechanism. Carotenoids are separated on a C8 solid support in an isocratic mode using a mobile phase consisting of a mixture of tetrahydrofuran and water in a volumetric ratio of 70:30. Detection of the separated carotenoids, lutein, and lycopene, is performed using a spectrophotometric detector at a wavelength of 450 nm or a diode array detector in the wavelength range from 190 to 600 nm. Identification and quantitative calculation of the peaks of separated carotenoids are carried out at the absorption maximum of 450±5 nm, enhancing the selectivity of chromatographic measurement. The approximate retention time for lutein is 4.6±0.1 minutes, and for lycopene, it is 13.0±0.1 minutes.

Statistical processing of the experimental data was carried out in Microsoft Excel 2010 (Microsoft Corp., USA). The comparison of the sample arithmetic means was carried out with Student's t-test. The critical level of significance (p) in testing statistical hypotheses was assumed to be 0.05. Quantitative data in the article have the format of M±SE where M is the mean value and SE is the standard error.

RESULTS AND DISCUSSION

Vitamin C (L-Ascorbic acid) is not synthesized in the human organism, so it is vital to ensure its regular intake with food [30-32]. Vitamin C is an enzyme cofactor for biochemical reactions, catalyzed by monooxygenases, dioxygenases and oxygenases with mixed function. It is part of the antioxidant system of the human body and plays a significant role in the biosynthesis of collagen, carnitine and catecholamines as well as in the assimilation of iron from food. Moreover, it participates in the metabolism of cholesterol [31, 33], promotes the maintenance of various cellular functions as innate and adaptive immune systems, including changes in susceptibility to various viral infections and the effect on inflammatory processes [34, 35]. It has been established that a diet rich in vitamin C serves not only as a means of prevention but can also be effective in cases of severe COVID-19 infection, since ascorbic acid helps to reduce the number of inflammatory mediators (i.e. interleukin-6 and endothelin-1) causing pneumonia and respiratory diseases, especially in adult patients with hypertension and diabetes [36]. Simultaneously, the best digestibility of vitamin C is observed within the presence of several macro- and microelements and phytochemicals that are part of natural products of processed raw plant-based materials, which is most effective for human health [37].

The Average Requirement (AR) for vitamin C in the human body necessary to compensate its daily losses is 90 mg/day for men and 80 mg/day for women. At the

same time, the recommended consumption rates (Dietary Reference Intake - PRI) for men and women over 18 are 110 mg/day and 95 mg/day, respectively [33].

The amount of vitamin C in tomatoes varies widely: 6-23 mg/100 g FW (fresh weight) in cultivated varieties and 6-50 mg/100 g FW in wild varieties [38]. Scientists are working on the biofortification of tomato fruits with vitamin C [38-41].

The results of determination of vitamin C content in the researched samples of tomato fruits (Table 2) showed that the largest amount of it accumulated during cultivation in the Voronezh region of the Russian Federation. Such a result can be considered natural, since the high illumination during the growth season of tomatoes contributes to the accumulation of vitamin C in fruits [31, 38, 42]. The Voronezh Region is characterized by a temperate continental climate with moderately hot summers and 46.7-64.5 % sunny days between May and September (Figure 2); the warmest month is August with an average maximum daytime temperature +26.8 ºC. The Minsk region of Belarus is also located in a temperate continental climate zone, but it is characterized by a significant influence of Atlantic Ocean air, which leads to a decrease in the number of sunny days to 36.7-48.4 % (the warmest month is July with an average maximum daytime temperature +23 ºC).

Table 2. The content of vitamin C (L-ascorbic acid) in tomato fruits, mg/100 g FW.

Name of the variety	Republic of Belarus	Russian Federation	
		the village of Khokhol	the village of Nikonovo
Red - fruited tomatoes:			
Budenovka	0.13±0.03	0.44±0.11	13.29±3.32
Bull 's forehead	0.13±0.03	0.13±0.03	2.03±0.51
Bull 's Heart	below detection limit		0.89±0.22
Volgogradskiy skorospelyi	0.29±0.07	0.95±0.24	1.42±0.35
Yellow - fruited tomatoes:			
Orange	0.10±0.2	0.26±0.06	below detection limit
Dark - hued tomatoes:			
Viagra	0.12±0.03	20.57±5.14	17.25±4.31
The Black Prince	below detection limit	1.87±0.47	3.04±0.76
Black Heart of bull	0.33±0.08	0.31±0.08	3.62±0.90
Chocolate	0.18±0.04	13.46±3.36	13.16±3.29

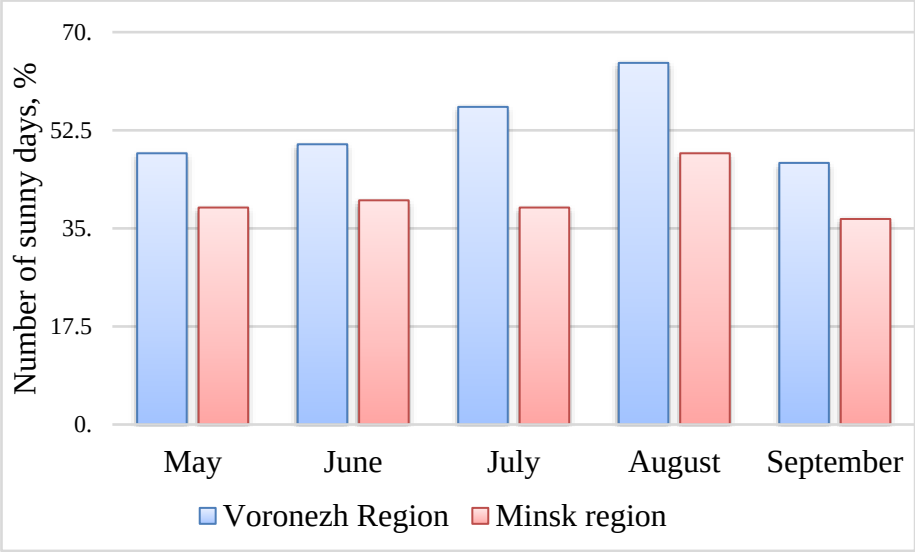


Figure 2. Comparison of the number of sunny days in the Voronezh region of the Russian Federation and of Minsk region of the Republic of Belarus (May-September) (https://anyroad.ru/city/weather/воронеж,воронежская-область; https://anyroad.ru/city/weather/минск,by).

The fruits of tomatoes of dark- hued varieties with the highest content of vitamin C were *Viagra* (20.57 and 17.25 mg/100 g) and *Chocolate* (13.46 and 16.16 mg/100 g), grown in the villages of Khokhol and Nikonovo of the Voronezh region, Russian Federation. Among the red - fruited varieties, only the *Budenovka* variety can be emphasized, grown in the village of Nikonovo (13.29 mg/100 g).

The data obtained confirms the presence of high variability in the content of vitamin C in tomatoes, depending on the place of their growth, soil composition, use of mineral fertilizers, agrotechnical techniques, illumination, variety, vegetation period (degree of maturity), conditions and shelf life of fruits [32].Synergistic interacting carotenoids give special value to tomato fruits: lycopene and lutein have a powerful antioxidant effect [43].

It is known that tomatoes are the main source of lycopene for humans, providing up to 85 % of its intake with food. The bioavailability of lycopene in tomato byproducts (tomato paste, tomato juice, etc.) is higher than in fresh tomatoes, since during the technological processing a transition of the native trans-isomeric form of lycopene to a cis isomer occurs, which is more easily absorbed by the human body [15, 44-46]. It is known that the color of lycopene is directly related to its isomeric form. Completely trans-isomer and most of the other isomers of lycopene have a red color, while tetra cis lycopene has an orange hue [47]. The content of lycopene in tomato fruits varies in a wide range; according to Løvdal T.C. et al., it is limited by the interval 0.03–20.2 mg/100 g [12], while according to the data [48] which mentions the range 0.04-27.0 mg/100 g. It is commonplace that the amount of lycopene in tomatoes significantly depends on the varietal characteristics and geography of the region [49-51], growing conditions and the degree of fruit maturity [52-55], as well as the conditions of their storage and transportation [12].

With the help of genetic engineering technologies, tomatoes with an increased lycopene content of 200-300 % were obtained [20, 56].

The amount of lycopene present in processed foods are often significantly higher than in fresh tomatoes, which is explained by the removal of moisture from the fruit before obtaining semi-finished products with a higher concentration of it. According to Rao A.V., in

ketchup, the amount of lycopene was in the range of 9.9-13.44 mg/100g, whereas in fresh fruits it was 0.88-7.74 mg/ 100g [57]. In tomato puree, the lycopene content increases to 12.7-23.46 mg/100 g FW (fresh weight) [58, 59], in pasta – up to 32.1-57.87 mg/100 g FW [3, 40], and in dried tomatoes – up to 112.63-126.49 mg/100 g FW [60].

The importance of lycopene in maintaining human health is highly acknowledged, particularly, in the prevention of cardiovascular diseases (atherosclerosis, arterial hypertension) [15, 61] and inhibition of human cancer cell growth [43]. Daily consumption of 2-20 mg of lycopene improves blood pressure, endothelial functions, and metabolic profile [15]. The form in which lycopene enters the human body is also important. More beneficial effects were observed when taking food with tomato products containing lycopene, than when taking dietary supplements with lycopene [61].

It was established that the higher level of solar radiation and temperature in the Voronezh region of the Russian Federation positively correlates with the amount of lycopene in tomatoes (table 3). The exception was *The Black Prince* variety: when grown in Belarus, the content of lycopene in it was 2.1-2.6 times more than in fruits grown in the Voronezh region of the Russian Federation.

Significant fluctuations in the content of lycopene were noted in tomatoes grown in the Voronezh region of the Russian Federation: among red–fruited tomatoes, the minimum content of lycopene (3.02 mg/100 g FW) was noticed in *Budenovka* (village of Khokhol), and the largest concentration (27.06 mg/100 g FW and 25.82 mg/100 g FW)- in varieties *Volgogradskiy skorospelyi* (village of Nikonovo) and *Bull's heart* (the village of Khokhol). Among the dark- hued fruits of tomatoes, the highest concentration of lycopene was observed in the variety *Black Heart of bull* (23.40-25.77 mg/100 g FW), with a slight fluctuation depending on the growing area (~10 %). In all analyzed varieties of dark- hued tomatoes grown in the village of Nikonovo, the lycopene content was higher than that of the samples grown in the village of Khokhol, Voronezh region, the *Viagra* and *Chocolate* varieties having a difference of 85.6% and 108.5%, respectively.

Table 3. Lycopene content in tomato fruits, mg/100 g FW.

Name of the variety	Republic of Belarus	Russian Federation	
		the village of Khokhol	the village of Nikonovo
Red - fruited tomatoes:			
Budenovka	0.40±0.10	3.02±0.75	7.19±1.80
Bull 's forehead	0.20±0.05	9.66±2.41	5.59±1.40
Bull 's heart	0.20±0.05	25.82±6.45	11.45±2.86
Volgogradskiy skorospelyi	1.35±0.34	4.40±1.10	27.06±6.76
Yellow - fruited tomatoes:			
Orange	below detection limit		
Dark - hued tomatoes:			
Viagra	0.55±0.01	3.76±0.94	6.98±1.74
The Black Prince	29.14±7.28	11.09±2.77	14.01±3.50
Black Heart of bull	9.27±2.32	23.40±5.85	25.77±6.44
Chocolate	<0.20	2.36±0.59	4.92±1.23

In general, the range of lycopene content in the analyzed samples of red-fruited and dark- hued tomatoes (<0.20–27.06 mg/100 g FW) presented in table 4 is comparable with the results published by Løvdal T. et al. [12], where 126 varieties of tomatoes from 8 countries (Norway, Poland, USA, Hungary, Spain, Italy, India, Canada) showed a range from 0.03 to 20.20 mg of lycopene/100 g. It is also comparable with the results of Adalid et al. [48], where 49 different tomato samples from 24 countries on four continents showed a range of lycopene from 0.04 to 27.0mg per 100g.

Literature indicates that lycopene either does not accumulate in yellow-fruited tomatoes or is present in significantly smaller quantities than in red-fruited and dark- hued fruits [62]. In all samples of the variety *Orange*, regardless of the growing region, lycopene was not detected, which may indicate the genetic characteristics of this variety [63]. Lutein and its isomer zeaxanthin help strengthen the vessels' walls and increase their elasticity, as well as improve vision [64-67].

The lutein content varies significantly depending on the color of tomato fruits [49]. Flores P. et al. examined the content of carotenoids, including lutein in yellow, pink, and red tomatoes, and in fruits of black color with yellow, pink, or red background color. In the fruits of tomatoes of yellow color, the lutein content varied in the interval 90-249 mcg/kg FW, yellow black – 214-310 mcg/kg FW, pink – 93-172 mcg /kg FW, pink and black – 186-190 mcg/kg FW, red – 140-321 mcg/kg FW, red-black 155-522 mcg/kg FW [62], respectively.

Currently, work is underway on biofortification of tomato fruits with carotenoids (including lutein and zeaxanthin) using metabolic engineering methods [65]. A new variety of tomatoes called "Xantomato" has been created [68].

The results of determining the lutein content in tomato fruits, shown in Table 4, indicate its variation in the range of <0.01- 0.28 mg/100 g FW. At the same time, lutein accumulates in large quantities in the fruits of tomatoes, grown in the Voronezh region of the Russian Federation (the exceptions are the red-fruited *Budenovka* and the dark- hued *The Black Prince* varieties), regardless of their color. The data obtained indicate that there is no unambiguous correlation between the lutein content and the tomato variety or the region of their cultivation. This circumstance is due to the high variability of the profile and concentration of carotenoids (including lutein) depending on external factors, especially in combination with varietal characteristics [62].

Table 4. Lutein content in tomato fruits, mg/100 g FW.

Name of the variety	Republic of Belarus	Russian Federation	
		the village of Khokhol	the village of Nikonovo
Red - fruited tomatoes:			
Budenovka	0.04±0.010	0.03±0.007	0.06±0.015
Bull 's forehead	<0.01	0.02±0.005	0.04±0.010
Bull 's heart	0.05±0.012	0.28±0.07	0.16±0.04
Volgogradskiy skorospelyi	0.01±0.002	0.19±0.047	0.13±0.032
Yellow - fruited tomatoes:			
Orange	0.01±0.002	0.05±0.012	0.04±0.010

Name of the variety	Republic of Belarus	Russian Federation	
		the village of Khokhol	the village of Nikonovo
Dark - hued tomatoes:			
Viagra	0.03±0.007	0.05±0.012	0.04±0.010
The Black Prince	0.24±0.060	0.08±0.020	0.08±0.020
Black Heart of bull	0.03±0.007	0.21±0.052	0.18±0.045
Chocolate	0.01±0.002	0.14±0.035	0.09±0.022

The importance of macro- and microelements in ensuring the vital processes of all human body systems is undeniable. They act as cofactors for enzymatic systems, are involved in the catalysis of numerous chemical reactions and essential for normal protein, fat, and carbohydrate metabolism. Macro- and microelements also prevent APA damage, are part of the DNA, regulate hormone levels, strengthen the bones, support the functioning and appearance of the skin, etc. [69-72].

Phosphorus and calcium are the bases of bone tissue. Potassium is necessary for the normal functioning of the body due to Na-K pump. Magnesium is involved in more than 600 enzymatic reactions in the nervous system, including energy metabolism and protein synthesis. Iron participates in the process of blood formation. Manganese activates the work of several enzymes [72-75].

Characteristics of the needs of an adult in the listed minerals, documented in the Russian Federation, the Republic of Belarus, and European countries, are shown in the Table 5.

Table 5. Characteristics of the needs of an adult in certain minerals.

Certain minerals	**Norms of physiological needs, mg/day**		**Population reference intakes (PRI), mg/day [33]**	**Adequate intakes (AIs), mg/day [33]**
	Russian Federation [76]	Republic of Belarus [77]		
	18–65 years old	18–59 years old	over 25 years old	
Ca	1000 (men) 1200 (women)	1000	950	-
P	700	800	-	550
Mg	420	400	-	350 (men) 300 (women
K	3500	2500	-	3500
Fe	10 (men) 18 (women)		11 (men) 16 (women)	-
Mn	2		-	3.0

The results of determining the content of some macro- and microelements in the fruits of tomatoes of the analyzed varieties presented in Table 6 are more or less consistent with the data published by Rosa-Martínez E. et al. [17] and Verde Méndez C.M. et al. [78], connected to the research of the composition of 10 varieties of tomatoes grown in Burriana (Valencia region, Mediterranean coast of Spain) in the condition of organic farming and to the research of the composition of 6 samples of red-fruited tomatoes purchased in supermarkets in Madrid (Spain), respectively.

Potassium predominates as the primary element among the constituents found in tomato fruits. It follows from the data in Table 6 that all the tomato samples we studied, regardless of the variety and region of cultivation, contained significantly more potassium than the samples examined by Rosa-Martínez E. et al. [17]. At the same time, red-fruited tomatoes of the *Budenovka* and *Black Heart of bull* varieties (Khokhol village of the Voronezh region of the Russian Federation), as well as dark- hued tomatoes of the varieties *Black Heart of bull* and *Chocolate* (Russian Federation) contained more potassium than the samples analyzed by Verde Méndez C.M. et al. [78].

Table 6. The mineral content in tomato fruits depending on the geography of the growing region.

Name of the tomato variety	**Mass fraction, mg/kg**					
	Macronutrients:				Trace elements:	
	potassium	calcium	magnesium	phosphorus	manganese	iron
***Tomatoes grown in Burriana (Valencia region, Spain)* [17]:**						
10 samples of red-fruited tomatoes without specifying the variety	900.1±128	70.8±17.8	64.5±15.7	158.9±24.3	did not define	1.81±0.51
***Tomatoes purchased in supermarkets in Madrid (Spain)* [78]:**						
6 samples of red-fruited tomatoes without specifying the variety	2660±250	69.6±6.4	76.4±0.7	did not define	0.56±0.19	0.87±0.27
Tomatoes grown in the Minsk region of the Republic of Belarus:						
Budenovka	1870±108	72±4.3	80±4.8	211±13.0	0.58±0.04	1.3±0.1
Bull 's forehead	2375±123	41±2.5	92±5.5	267±16.0	0.79±0.03	1.9±0.2
Bull 's heart	1965±102	49±2.9	84±5.0	228±14.0	0.59±0.02	1.2±0.1
Volgogradskiy skorospelyi	2820±128	39±2.3	106±6.4	389±23.0	0.71±0.02	2.1±0.2
Orange	2200±132	48±2.9	84±5.0	259±15.0	0.94±0.06	2.2±0.13
Viagra	2555±120	48±2.9	85±5.1	325±20.0	0.79±0.03	2.0±0.2
The Black Prince	2495±118	41±2.5	92±5.5	306±18.0	0.81±0.03	2.5±0.2
Black Heart of bull	2610±123	37±2.2	119±7.1	336±20.0	0.78±0.03	2.4±0.2
Chocolate	2475±129	70±4.2	103±6.2	318±19.0	0.99±0.05	4.0±0.3
Tomatoes. grown in the village of Khokhol in the Voronezh region of the Russian Federation:						
Budenovka	4235±140	196±11.0	170±10.2	535±32.0	1.13±0.05	5.8±0.4
Bull 's forehead	2270±106	125±7.2	104±6.0	187±11.0	0.63±0.04	4.0±0.3
Bull 's heart	3135±201	69±4.1	140±8.4	370±22.0	0.84±0.04	2.8±0.2
Volgogradskiy skorospelyi	2665±122	160±9.6	116±7.2	324±19.0	0.73±0.03	4.2±0.3
Orange	did not define					

Name of the tomato variety	Mass fraction, mg/kg					
	Macronutrients:				Trace elements:	
	potassium	calcium	magnesium	phosphorus	manganese	iron
Viagra	2620±109	86±5.2	94±5.6	380±23.0	0.66±0.04	2.9±0.2
The Black Prince	2700±101	59±3.6	120±7.2	410±25.0	0.96±0.04	3.5±0.2
Black Heart of bull	3485±139	187±11.4	131±7.8	358±22.0	0.84±0.04	5.5±0.4
Chocolate	3030±132	102±6.0	124±7.2	429±26.0	0.89±0.04	3.9±0.2
Tomatoes grown in the village of Nikonovo, Voronezh region of the Russian Federation:						
Budenovka	2560±103	168±10.2	104±6.0	305±19.0	0.47±0.02	4.7±0.3
Bull 's forehead	2475±104	86±5.2	125±7.2	361±22.0	0.97±0.04	4.3±0.3
Bull 's heart	2765±108	130±7.8	120±7.2	340±20.0	0.87±0.04	5.0±0.4
Volgogradskiy skorospelyi	2710±108	107±6.0	124±7.2	320±22.0	0.62±0.04	4.3±0.3
Orange	2800±163	161±9.6	120±7.2	316±19.0	0.53±0.03	7.0±0.03
Viagra	2645±102	52±3.1	82±4.9	292±17.0	0.39±0.02	1.9±0.1
The Black Prince	2690±102	97±5.8	120±7.2	362±22.0	1.03±0.05	4.5±0.3
Black Heart of bull	3460±128	98±5.9	150±9.0	340±20.0	0.69±0.04	3.7±0.2
Chocolate	3590±129	60±3.6	99±5.9	314±19.0	0.31±0.02	1.9±0.1

In terms of calcium content, a distinct pattern emerged: tomatoes grown in the Republic of Belarus (with the exception of *Budenovka* and *Chocolate* varieties) and *Viagra* variety tomatoes (from the village of Nikonovo) exhibited lower calcium levels compared to Spanish tomatoes [17, 78]. Conversely, tomatoes of the *Budenovka* variety, *Volgogradskiy skorospelyi*, and *Black Heart of bull (Russian Federation)*, *Bull's Forehead*, and *Chocolate* (Khokhol village in the Voronezh region of the Russian Federation), *Bull's Heart*, and *The Black Prince* (village of Nikonovo, Voronezh region of the Russian Federation) surpassed the calcium values found in Spanish tomatoes. According to the magnesium content, tomatoes grown in the Republic of Belarus were comparable to Spanish tomatoes (excess values were observed only in varieties *Volgogradskiy skorospelyi*, *Black Heart of bull* and *Chocolate*), and in tomatoes grown in the Russian Federation, higher values of this element were observed regardless of the growing region (with the exception of the *Viagra* variety, *Budenovka* and *Chocolate* (village of Nikonovo, Voronezh region of the Russian Federation). In general, the accumulation of magnesium was higher in the fruits of tomatoes grown in the regions of the Russian Federation, which, apparently, is associated with good soil conditions.

In terms of phosphorus content, all tomatoes analyzed by us, regardless of the variety and region of cultivation, were superior to Spanish tomatoes, and the manganese content was comparable to or slightly exceeded the values of Spanish tomatoes (with the exception of tomatoes of the variety *Black Heart of bull* and *Chocolate*, grown in the village of Nikonovo of the Russian Federation). Consumption of 100 g of tomatoes of the variety *Budenovka*, grown in Khokhol, fulfils the daily consumption norm (7%) of phosphorus for adults.

In terms of iron content, tomatoes grown in the Republic of Belarus were comparable to the Spanish ones [17] (only in tomatoes of the variety *Chocolate* an excess of almost 2 times was observed), whereas Russian tomatoes (except for varieties *Viagra* and *Chocolate*, grown in the village of Nikonovo) were significantly outnumbered. The range of the obtained values of the

mass fraction of iron in tomato fruits varied from 1.2 mg/kg (variety *Bull's heart*, Republic of Belarus) up to 7.0 mg/kg (variety *Orange*, village of Nikonovo).

Significant fluctuations in the mineral composition are largely determined by the different composition of the soils on which tomatoes were grown, as well as the applied agrotechnical techniques.

To ensure a normal functioning of the body, both the content of essential elements in the diet and their ratio are important. This is especially true for the optimal ratio of calcium and magnesium, calcium, and phosphorus. Excess phosphorus leads to the excretion of calcium from bone tissue, excess calcium contributes to the development of urolithiasis, and excess magnesium reduces the absorption of calcium in the human body [73].

The optimal ratio of calcium/phosphorus and calcium/magnesium for the adult population is the ratio of 1:1.5 and 1:0.7, respectively [77]. If this ratio is violated, phosphorus begins to accumulate and is not excreted from tissues and bones. If the amount of phosphorus exceeds the level of calcium in food by more than twice, then soluble salts are formed, passing from bone tissue into the blood. Calcium enters the walls of blood vessels, which causes their fragility [73, 77, 79].

Inferring from the presented data, in the optimal correlation (1:1.5) calcium and phosphorus are found in tomatoes of the variety *Bull's forehead* (1:1.5) and *Black Heart of bull* (1:1.9), grown in the village of Khokhol, and also in tomatoes of the variety *Budenovka* (1:1.8, the village of Nikonovo).

The optimal ratio of calcium and magnesium for assimilation (1:0.7) is observed in the fruits of tomatoes grown in the village of Khokhol of the Russian Federation – varieties *Volgogradskiy skorospelyi* and *Black Heart of bull* (1:0.7), *Bull´s forehead* (1:0.8), *Budenovka* (1:0.9) and grown in the village of Nikonovo – varieties *Budenovka* (1:0.6), *Orange* (1:0.7) and *Bull´s heart* (1:0.9).

In all other samples studied, there is an excess of phosphorus and magnesium. The data obtained should be considered when selecting foods for inclusion in the daily diet of an adult.

CONCLUSION

The scientific novelty of the presented study lies in the pursuit of acquiring novel experimental data related to the quantity of biologically active substances (including vitamin C, lycopene, lutein, macro- and microelements) in tomato fruits. This exploration takes into account varietal characteristics and the region of cultivation, providing insights that can optimize the efficient utilization of these compounds in functional nutrition. Based on the experimental data obtained, it is established:

The highest content of vitamin C is in the fruits of tomatoes of *Viagra* varieties (20.57 mg/100 g FW and 17.25 mg/100 g FW) and *Chocolate* (13.46 mg/100 g FW and 13.16 mg/100 g FW), grown in the villages of Khokhol and Nikonovo of the Voronezh region of the Russian Federation, respectively, and also in sorts *Budenovka* (13.29 mg/100 g FW), grown in the village of Nikonovo.

The largest amount of lycopene is in the fruits of tomatoes of the variety *The Black Prince* (29.14 mg/100 g FW), grown in the agro-town of Samokhvalovichi of the Republic of Belarus, varieties of *Volgogradskiy skorospelyi* (27.06 mg/100 g FW), grown in the village of Nikonovo, *Bull's heart*, grown in the village of Khokhol of the Voronezh region of the Russian Federation and variety *Black Heart of bull* (23.40 mg/100 g FW и 25.77 mg/100 g FW), grown in the villages of Khokhol and Nikonovo, respectively.

Fruits of tomato varieties *The Black Prince* (agro-town of Samokhvalovichi), *Chocolate, Black Heart of bull* and *Bull's heart* (Khokhol, Russian Federation) contained a large amount of lutein (0.24; 0.14; 0.21 and 0.28 мг/100 FW accordingly).

Tomatoes of the variety *Budenovka*, grown in the village of Khokhol of the Russian Federation, have a high mineral saturation; tomatoes of varieties *Bull's heart и Black Heart of bull*, grown in the same region, are also rich in macro- and microelements (K, Ca, Mg, P, Mn, Fe).

Optimal ratio of calcium and phosphorus (1:1.5) is noticed in varieties *Bull's forehead, Black Heart of bull, Budenovka;*

Optimal ratio of calcium and magnesium (1:0.7) is noted in the fruits of tomato varieties *Volgogradskiy skorospelyi, Bull's forehead, Budenovka, Black Heart of bull, Bull's heart, Orange,* grown in the regions of the Russian Federation.

Thus, due to the presence of biologically active substances, particularly of lycopene, lutein, vitamin C and minerals (potassium, calcium, magnesium, phosphorus), tomatoes can serve as their source in the development of functional products, including those aimed at preventing cardiovascular diseases [5, 6, 80, 81]. It should be noted that the accumulation of certain biologically active compounds in tomato fruits significantly depends on the variety and conditions of their cultivation.

List of Abbreviations: FW, fresh weight; AR, average requirement; PRI, Population reference intakes; AIs, Adequate intakes, APA, Adenosine Phosphoric acid; DNA, Deoxyribonucleic Acid.

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Authors' contributions: IZ, IPoch and NA discussed the idea of studying the content of biologically active compounds in tomatoes depending on the color of the fruit and the place of their cultivation and developed the study design. IZ, IPoch, DE, IPl provided the collection of tomato fruit samples for the study. IPoch provided the experimental part of the work. IPoch, IZ, IPl, NA edited and finalized the manuscript for submission. ZI, AC, AP systematized the data and analyzed the results. DE, IPl contributed to writing the abstract and introduction.

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