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Importance of using tomato serum in the development of functional food products

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ABSTRACT

Background: The significance of incorporating tomatoes in the development of functional food products is due to their content of vitamins, carotenoids, and minerals. In industrial tomato processing, a considerable amount of tomato serum (clarified tomato juice) is produced. For instance, during tomato paste production, serum constitutes 80% of the total volume of processed tomatoes. Tomato serum contains essential organic, phenolic, and polyphenolic compounds, water-soluble vitamins, macro and microelements. One promising application is the use of tomato serum in yeast bread technology. A specific application is using it as a growth stimulator for baker's yeast, as well as for microorganisms in sourdoughs, including Type I wheat-based sourdough. This is an effective method to enhance the biotechnological characteristics of sourdoughs, as well as the organoleptic and physico-chemical quality indicators of bakery products, including enriched and functional products. The aim of the study is to investigate the mineral composition of tomato serum from red-fruited, yellow-fruited, and dark-hued tomatoes, as well as flour from various industrial producers of premium-grade baking wheat flour, for their potential combined use in the production of enriched and functional bakery products.

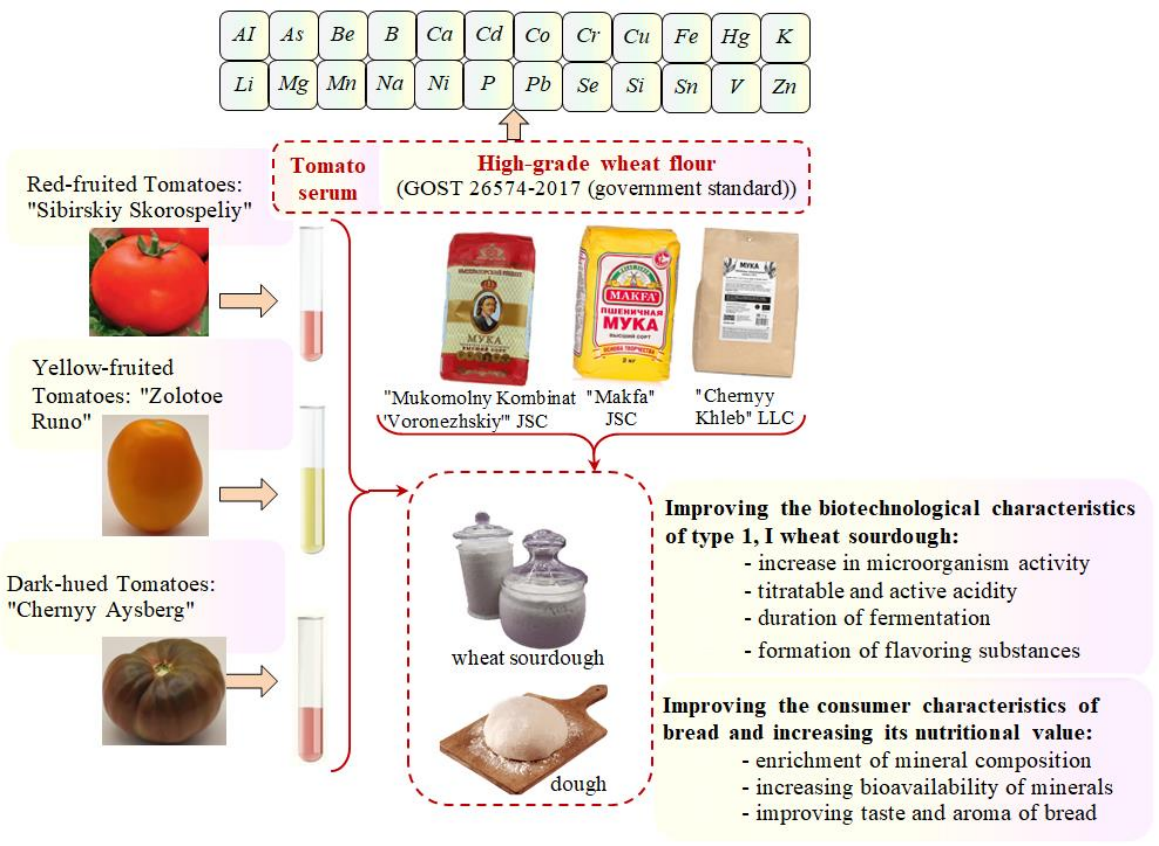
Objective: Tomato serum was obtained under laboratory conditions by centrifuging pre-crushed and thermally processed fruits of the red-fruited variety "Sibirskiy Skorospeliy," yellow-fruited variety "Zolotoye Runo" and dark-hued variety "Chernyy Aysberg." The tomatoes were grown in 2023 in open fields in the village of Nikonovo, Voronezh Voronezh region, Russian Federation. The mineral composition of tomato serum from various tomato varieties and premium-grade wheat flour from different industrial producers (JSC "Mukomolny Kombinat 'Voronezhskiy'", JSC "Makfa", and LLC "Chernyy Khleb", Russia) was investigated.

Methods: The mineral content was determined using inductively coupled plasma mass spectrometry with a quadrupole mass spectrometer, Nexion 300 D. The basic physicochemical quality indicators of the high-grade wheat flour were rapidly assessed using the "Chopin Technologies Infraneo chopin" device.

Results: The dry matter content in tomato serum ranges from 4.8% to 6.1%. All tomato serum samples exhibited an acidic reaction: the "Sibirskiy Skorospeliy" variety was the most acidic at pH 3.90, "Chernyy Aysberg" had a pH of 3.99, and "Zolotoye Runo" was the least acidic at pH 4.37. The content of 24 mineral elements was determined in both tomato serum and premium-grade wheat flour. Tomato serum from various tomato varieties contains a broad range of minerals. Potassium is the most abundant (2,755.5-3,274.5 mg/kg), with its content being 1.3-2.1 times higher than in premium-grade wheat flour. Significant amounts of phosphorus (275.8-279.0 mg/kg), magnesium (116.3-146.4 mg/kg), and calcium (63.88-91.61 mg/kg) are also present in the serum. Iron content varies from 2.533 mg/kg (variety "Chernyy Aysberg") to 17.630 mg/kg (variety "Sibirskiy Skorospeliy"). In premium-grade wheat flour from JSC "Mukomolny Kombinat 'Voronezhskiy'" and JSC "Makfa", iron content is 9.109-9.643 mg/kg, while in the sample from LLC "Chernyy Khleb," it is 2.29-2.43 times higher. Zinc content in tomato serum and industrial wheat flour ranges from 1.921-2.685 mg/kg and 8.12-9.429 mg/kg, respectively. Consuming 100 g of tomato serum can meet 7.9-9.4% of the daily potassium requirement, 2.8-3.5% of magnesium, 4.7-9.8% of iron, and 3.9-4.0% of phosphorus. Sodium content in tomato serum is minimal, ranging from 23.74 to 68.11 mg/kg, which is 0.2-0.5% of the daily requirement for an adult.

Conclusion: Incorporating tomato serum into food products, including bakery goods, can enrich their composition with deficient macro- and microelements and improve the bioavailability of minerals in flour. A specific application of tomato serum could be as a growth stimulator for wheat sourdough microorganisms (including type 1, I), which is an effective way to enhance the biotechnological properties of baker’s sourdoughs, thereby improving their functionality and the organoleptic and physico-chemical quality of bakery products.

Keywords: tomato serum, clarified tomato juice, wheat flour, micro- and macro-element composition, functional properties.



INTRODUCTION

The last 5-10 years have been marked by significant achievements in the field of functional food science. This progress has been made possible by the vast number of studies conducted in thousands of organizations across various regions of the globe. Both traditional approaches to developing functional food recipes [1-3] and innovative ones, such as those combining the possibilities of quantum and tempus theories of functional food science, are being utilized [4]. A mandatory attribute that qualifies a food product as functional is the presence of substances or compounds with biological activity that contribute to the prevention of specific diseases [4, 5]. Sources of biologically active compounds can include not only "pure" preparations obtained through microbiological or chemical synthesis but also processed products from various fruits, berries, and vegetables, including tomatoes [6-11].

The importance of tomatoes in developing functional food products is primarily due to their content of vitamins (particularly vitamin C), carotenoids (such as lycopene and lutein), and minerals (notably potassium, calcium, magnesium, and phosphorus) [8, 9, 11-17]. Additionally, it's important to consider that tomatoes are used to produce popular and commercially successful products such as tomato juice, paste, and various sauces. By-products from tomato processing, such as pomace consisting of seeds, skins, and minimal pulp, also hold interest for the food industry, with various recommendations for their use or processing [18, 19].

One traditional tomato-processing product is tomato juice, which always contains a certain amount of pulp. Some industrial tomato processing methods produce serum (clarified juice, cell juice, or juice without pulp), which has not yet achieved widespread commercial popularity as a standalone product. The volumes of tomato serum produced during processing are substantial; for example, in tomato paste production, serum can make up to 80% of the processed tomato volume. Tomato serum typically contains 6.0-8.0% dry matter, including sugars, organic and phenolic acids, polyphenolic compounds, water-soluble vitamins, and macro- and microelements. One of the first steps in developing functional food products is justifying the choice of raw materials based on the presence of specific biologically active compounds [1, 2].

The aim of the study is to investigate the mineral composition of tomato serum from red-fruited, yellow-fruited, and dark-hued tomatoes, as well as flour from various industrial producers of premium-grade baking wheat flour, for their potential combined use in the production of enriched and functional bakery products.

MATERIALS AND METHODS

Materials: The subjects of the study were fruits of the red-fruited tomato variety "Sibirskiy Skorospeliy," the yellow-fruited variety "Zolotoe Runo," and the dark-fruited variety "Chernyy Aysberg" (Table 1). The tomatoes were grown in 2023 in open fields in the village of Nikonovo, Voronezh Region, Russian Federation. Tomato serum was obtained under laboratory conditions by centrifuging pre-chopped and thermally processed tomato fruits. For comparison, the mineral composition of high-grade wheat flour (GOST 26574-2017 (government standard)) from JSC "Mukomolny Kombinat 'Voronezhskiy'", JSC "Makfa," and LLC "Chernyy Khleb" (Russia) was also analyzed.

Table 1: Characteristics of tomatoes used in the work.

Variety	Fruit Appearance	Fruit Characteristics
Red-fruited Tomatoes: "Sibirskiy Skorospeliy"		The fruits are bright red in color, with a flat-round and round shape. They are medium-sized, weighing 65-114 g. The variety is maturing early. The originators are the Federal Scientific Center for Vegetable Growing (Moscow Region, Odintsovo District, VNIISSOK Settlement, Russia); Agrofirm Aelita LLC (Moscow, Russia); and Gavrish Breeding Company LLC (Moscow, Russia).
Yellow-fruited Tomatoes: "Zolotoe Runo"		Unripe fruits are light green, while ripe fruits are yellow. The shape is oval. The fruit weighs 90-100 g. The variety matures early. The originators are Agrofirm Poisk LLC (Moscow Region, Ramensky District, Vereya Village, Russia) and Tsentr-Ogorodnik LLC (Moscow Region, Ramensky District, Vereya Village, Russia).
Dark-hued Tomatoes: "Chernyy Aysberg"		Unripe fruits are green with a spot, while ripe fruits are purple, brown. The shape is flat-round and moderately ribbed. The fruit weighs 220-280 g. The variety is maturing early. The originator is Agrofirm Aelita LLC (Moscow, Russia).

Methods: Determination of dry matter content was performed using a refractometric method; active acidity was measured with a pH-150MI device (manufactured by LLC "Izmeritelnaya Tekhnika," Russia); and the quantity of mineral substances was determined by inductively coupled plasma mass spectrometry using a quadrupole mass spectrometer Nexion 300 D. The basic physicochemical quality indicators of the high-grade wheat flour were rapidly assessed using the "Chopin Technologies Infraneo chopin" device.

RESULTS AND DISCUSSION

All analyzed tomato serum samples were clear liquids, with colors corresponding to the tomato variety: bright yellow for serum from "Zolotoe Runo" tomatoes, pink for "Sibirskiy Skorospeliy," and light brownish pink for "Chernyy Aysberg." The dry matter content in tomato serum also varied: it increased in the order of "Zolotoe Runo", "Sibirskiy Skorospeliy", and "Chernyy Aysberg", with values of 4.8%, 6.0%, and 6.1%, respectively. All tomato serum samples had an acidic reaction: "Sibirskiy Skorospeliy" was the acidic at pH 3.90, "Chernyy Aysberg" was intermediate at pH 3.99, and "Zolotoe Runo" was the least acidic at pH 4.37.

Among the wide variety of chemical elements (currently 118 elements are known), about 20 are considered crucial for the proper biological functioning of the human body [20]. Mineral substances are one group of functional ingredients used in the production of functional foods due to the undeniable importance of macro- and micro-elements in supporting the life processes of all human body systems: they act as cofactors for enzymatic systems and participate in the catalysis of numerous chemical reactions. Theyare necessary for normal metabolism of proteins, fats, and carbohydrates, prevent damage from free radicals, are part of DNA, regulate hormone levels, strengthen bones, and support skin function and appearance, among other roles [20-23]. We determined the content of 24 chemical elements in tomato serum and high-grade wheat flour.

Since agricultural soils are at risk of contamination with toxic metals/metalloids due to anthropogenic activities, excessive accumulation of arsenic (As), cadmium (Cd), lead (Pb), and mercury (Hg) in food crops can occur [24, 25]. Therefore, it is important to consider that several chemical elements are crucial for assessing food safety due to their potential toxic effects on human health [26]. Among the ten major chemical substances of serious public health concern recognized by the World Health Organization, four are particularly hazardous: arsenic, cadmium, lead, and mercury [27]. Other international organizations, such as the Agency for Toxic Substances and Disease Registry (ATSDR), the United Nations Environment Programme (UNEP), and the U.S. Environmental Protection Agency (US EPA), also classify toxic heavy metals as substances with the highest risk to human health [28]. Accumulation of toxic elements in the human body disrupts essential metabolic processes. Comparison of the mechanisms of action of these toxic elements reveals similar pathways causing their toxicity: generation of reactive oxygen species, weakening of antioxidant defenses, enzyme inactivation, and oxidative stress [29, 30]. In addition to inducing oxidative stress, toxic heavy metals act as "molecular mimics" of certain endogenous intracellular molecules and inhibit several metabolic processes; they can cross the placenta and interfere with fetal development [28].

Chronic exposure to arsenic compounds leads to their accumulation in the body, with typical consequences including skin lesions and cancer [31]. Arsenic also affects the liver, kidneys, and lungs, and has some neurotoxic effects. Like nickel, arsenic participates in redox reactions that produce free radicals, which cause oxidative damage to proteins and DNA. Arsenic has a chemical similarity to the phosphate anion, disrupting oxidative phosphorylation and depleting cellular energy reserves. Inorganic arsenic and cadmium compounds are classified as Group 1 human carcinogens [28-29].

The human body has a limited ability to respond to cadmium exposure, as this metal does not undergo metabolic breakdown into less toxic compounds and is excreted only in small amounts. It affects every organ in the body, with its most severe effects including nephrotoxicity, osteotoxicity, teratogenicity, endocrine disruptions, hepatotoxicity, and carcinogenicity. Multiple mechanisms of cadmium-induced carcinogenesis include oxidative stress with inhibition of antioxidant enzymes, stimulation of lipid peroxidation, and interference with DNA repair systems [32]. Cases of microvascular damage to the brain from lipid peroxidation due to cadmium exposure have been noted. Cadmium can also alter the activity of many enzymes involved in carbohydrate metabolism [29]. Cadmium affects both male and female reproductive functions, disrupting hormone synthesis/regulation and decreasing pregnancy rates or outcomes [33]. Cadmium and lead can compete with zinc and replace it in proteins and enzymes, as well as interfere with calcium metabolism [28].

Lead primarily affects the hematopoietic, renal, reproductive, and central nervous systems [26]. Lead is well known to impair hemoglobin synthesis and affect erythrocyte morphology and survival [34].

Mercury and its compounds have severe toxic effects on the central nervous system and digestive system, suppress antioxidant defense systems, and contribute to the development of Alzheimer's disease and Parkinson's disease [29]. Mercury ions have a high affinity for cellular proteins, leading to nonspecific inhibition and damage of cellular enzyme systems [29].

Safety standards for arsenic, cadmium, lead, and mercury in processed grain products (flour) and vegetable juice products are outlined in Table 2, and in Table 3 - results of determining the content of toxic elements in tomato serum and wheat flour of the highest grade.

Table 2: Safety requirements for arsenic, cadmium, lead and mercury content.

Name of the toxic element	**Permissible levels, mg/kg, not to exceed**			
	in vegetable juice products		in processed cereal products	
	TR CU 021/2011	Regulation (EU) 2023/915	TR CU 021/2011	Regulation (EU) 2023/915
Lead	0.5	0.05	0.5	0.2
Arsenic	0.2	Not regulated	0.2	Not regulated
Cadmium	0.03	0.02	0.1	0.1
Mercury	0.02	Not regulated	0.03	Not regulated

Table 3: Results of determining the content of toxic elements in tomato serum and wheat flour of the highest grade.

Elements	Content, mg/kg:					
	in the serum from the pulp of tomatoes			in high-grade bakery wheat flour production		
	“Sibirskiy Skorospeliy”	**“Chernyy Aysberg”**	**“Zolotoe Runo”**	**"Mukomolny Kombinat 'Voronezhskiy'" JSC**	**"Makfa" JSC**	**"Chernyy Khleb" LLC**
As	0.00545± 0.0002	0.00554± 0.0009	0.00709± 0.0007	0.00542± 0.00006	0.01137± 0.0013	0.01264± 0.0008
Cd	0.00434± 0.0008	0.0023± 0.0002	0.01421± 0.0005	0.01039± 0.0011	0.00428± 0.0006	0.00685± 0.0006
Cr	0.03193± 0.0061	0.02109± 0.0010	0.02316± 0.0026	0.02304± 0.0017	0.02561± 0.0038	0.056± 0.0034
Co	0.00332± 0.0005	0.0024± 0.0003	0.0103±0.001	0.00319± 0.0008	0.00446± 0.0004	0.01053± 0.0006
Cu	0.4592± 0.0459	0.3273± 0.0327	0.8174±0.0817	1.62±0.162	2.687±0.2687	3.438± 0.3438
Hg	0.00373± 0.0005	0.00266± 0.0002	0.00442± 0.0004	0.01114± 0.0008	0.00723± 0.0004	0.00928± 0.0007
Mn	0.5497±0.026	0.4554± 0.0261	0.8574±0.0736	5.486±0.0751	6.001±0.5855	16.20± 0.29
Ni	0.04087± 0.0028	0.07379± 0.0659	0.1558±0.007	0.06576± 0.0044	0.1105±0.0202	0.2067± 0.0055
Pb	0.00762± 0.0006	0.01195± 0.0025	0.00905± 0.0003	0.01247± 0.0006	0.01355± 0.0003	0.02045± 0.002
Sn	0.4066± 0.0189	0.1003±0.001	0.2233±0.0151	0.03655± 0.0468	0.01545± 0.0017	0.00561± 0.00003

Comparison of experimental data (Table 3) with regulatory requirements (Table 2) shows that all analyzed samples of tomato serum and high-grade wheat flour meet safety standards for toxic heavy metals content.

In addition to the elements mentioned above, nickel (Ni), copper (Cu), manganese (Mn), cobalt (Co), chromium (Cr), and tin (Sn) also require attention and control [35-38]. There is evidence of a correlation between Ni and the development of breast cancer, chronic bronchitis, and allergic reactions [35, 37]. Although Cu, Mn, and Ni are trace elements necessary for normal life functions and homeostasis, in high doses they exhibit toxic properties. Additionally, Co^{2+} can substitute for Zn^{2+} in the zinc finger DNA-binding domain of the estrogen receptors (ERs) to associate with the estrogen response [35, 39]. It is reported that chromium (Cr) may contribute to the development of diabetic complications [37], and tin (Sn) can lead to a decrease in calcium levels in serum [38].

The data in Table 3 indicate the safety of the analyzed products in terms of toxic element content.

The determination of elements such as potassium, sodium, and calcium in juice products is important due to their dietary significance. For example, recent studies have confirmed that excessive sodium in food products is a factor contributing to cardiovascular diseases; sodium can either promote protective immunity (for example, by enhancing the body's response to skin pathogens) or contribute to immune dysregulation and the development of autoimmune diseases [40]. Calcium is essential for the human body but can pose problems for patients with renal insufficiency. Potassium is also

necessary for maintaining good health. Therefore, information about the levels of these elements is valuable. Phosphorus and calcium are fundamental to bone tissue, potassium is necessary for proper body function due to the Na-K pump, magnesium participates in over 600 enzymatic reactions, including energy metabolism and protein synthesis, regulates the nervous system, iron is involved in blood formation, and manganese activates several enzymes [20, 41]. Xiaoying Ye and colleagues have established that Se, Mg, and Fe play an important role in maintaining health of elderly individuals [42, 43]. Maryam Aryafar and co-authors have identified the protective role of adequate selenium and zinc intake in reducing the risk of dilated cardiomyopathy in children [44].

The results of the analysis of these and other important macro- and microelements in tomato serum and high-quality wheat flour are presented in Table 4.

Table 4: Results of Elemental Composition Analysis of Tomato Serum and High-Grade Wheat Flour.

Elements	**Content, mg/kg:**					
	in the serum from the pulp of tomatoes			in high-grade bakery wheat flour production		
	"Sibirskiy Skorospeliy"	**"Chernyy Aysberg"**	**"Zolotoe Runo"**	**"Mukomolny Kombinat 'Voronezhskiy'" JSC**	**"Makfa" JSC**	**"Chernyy Khleb" LLC**
Al	3.24±0.13	0.5177± 0.1337	1.505± 0.0959	3.086± 0.3757	2.103± 0.3404	4.519± 0.5691
B	0.7659± 0.05	0.6897± 0.093	0.6871± 0.0484	0.6682± 0.0369	0.7362± 0.0496	0.6045± 0.0782
Be	0.00013± 0.000003	0.00011± 0.000003	0.00007± 0.00001	0.00115± 0.0001	0.00045± 0.00006	0.0009± 0.0001
Ca	63.88±2.41	64.65± 5.910	91.61±2.992	206.80± 4.272	204.30±8.89	342.20± 15.52
Fe	17.63±0.76	2.533± 0.1555	8.438± 0.5049	9.109±1.264	9.643± 0.4746	22.09± 2.139
K	2,755.50± 109.21	3,058.80± 179.38	3,274.50± 282.28	1,568.10± 69.31	1,596.10± 127.70	2,181.20± 125.74
Li	0.02085± 0.0019	0.01926± 0.0032	0.00754± 0.0006	0.00802± 0.0009	0.02235±0.0009	0.05234± 0.0032
Mg	117.30± 6.15	116.30± 7.64	146.40± 11.54	246.20±5.31	268.70± 21.12	568.20± 47.58
Na	26.23±1.69	23.74± 2.4938	68.11±6.261	17.19±0.686	16.59±2.097	18.30± 1.04
P	277.70± 20.87	279.00± 13.09	275.80± 22.11	1,013.00± 6.93	905.80± 33.00	1,260.50± 193.70
Se	<0.00025	0.00393± 0.0003	<0.00025	0.04682± 0.0031	0.1262± 0.0089	0.3842± 0.0196
Si	1.60± 0.0506	1.509± 0.3037	1.70±0.0091	3.349± 0.3224	3.117± 0.3459	2.896± 0.4977
V	0.0022± 0.0004	0.0019± 0.0002	0.00167± 0.0002	0.00926± 0.0011	0.00735± 0.0006	0.01308± 0.0005
Zn	2.49±0.419	1.921± 0.222	2.685± 0.2026	9.429± 0.6358	8.12±0.499	19.81± 4.437

Tomato serum contains the highest amounts of potassium (2,755.5-3,274.5 mg/kg), phosphorus (275.8-279.0 mg/kg), magnesium (116.3-146.4 mg/kg), and calcium (63.88-91.61 mg/kg). Consuming 100 g of tomato serum can meet 7.9-9.4% of an adult's daily potassium requirement, 2.8-3.5% of magnesium, 4.7-9.8% of iron, and 3.9-4.0% of phosphorus. The iron content in tomato serum ranges widely: from 2.533 mg/kg ("Chernyy Aysberg" variety) to 17.630 mg/kg ("Sibirskiy Skorospeliy" variety). In wheat flour from industrial producers JSC "Mukomolny Kombinat 'Voronezhskiy'" and JSC "Makfa", the iron content is almost the same, ranging from 9.109 to 9.643 mg/kg. However, the flour sample from LLC "Chernyy Khleb " has iron content that is 2.29-2.43 times higher. Notably, the flour from LLC "Chernyy Khleb " has significantly higher levels of elements such as aluminum, calcium, chromium, copper, potassium, lithium, magnesium, manganese, sodium, nickel, lead, selenium, vanadium, and zinc compared to other flour samples. This is likely due to differences in the flour production process. LLC "Chernyy Khleb " uses a stone milling technology and labels the flour as "unbleached" (likely indicating that bran is not separated during milling). The high likelihood of bran presence in the flour from LLC "Chernyy Khleb " is supported by its whiteness, ash content, protein content, and water absorption capacity values (Table 5).

The potassium content in tomato serum is 1.3-2.1 times higher than in high-grade wheat flour, which is valuable from a nutritional perspective. Sodium levels in tomato serum are higher than in wheat flour but remain minimal, ranging from 23.74 to 68.11 mg/kg, which corresponds to 0.2-0.5% of the daily requirement for an adult.

Table 5: Results of express analysis of key physical and chemical quality indicators of high-grade wheat flour using the "Chopin Technologies Infraneo chopin" device.

Indicator	**Samples of wheat flour (name of the producing company)**		
	"Mukomolny Kombinat 'Voronezhskiy'"JSC	"Makfa" JSC	"Chernyy Khleb" LLC
Ash content, %	0.4	0.4	0.8
Moisture content, %	10.7	10.9	8.4
Protein content, %	11.8	13.2	14.3
Whiteness, conditional units	55.0	54.0	29.0
Water absorption capacity, %	58.4	54.7	63.4

Regular intake of zinc through food is crucial since this element cannot accumulate in significant amounts, and its deficiency leads to serious health issues [45, 46]. Zinc is essential for the activity of over 300 enzymes; zinc metalloenzymes play a crucial role in physiological processes including antioxidant, anti-inflammatory, and immune responses, as well as apoptosis [47]. Additionally, zinc serves as a structural component of bone tissue, participates in collagen matrix synthesis, and regulates intracellular signaling pathways in both innate and adaptive immune cells. It influences immune responses, including antibody production, inflammatory signaling, and lymphocyte differentiation. Zinc also plays a key role in the endocrine system and thyroid hormone metabolism, is essential for maintaining male fertility, supports the normal development and function of the

central nervous system, and helps preserve retinal cells, thereby reducing the risk of age-related macular degeneration [45]. Sources of zinc include fish, oysters, meat, legumes, nuts, whole grains, eggs, and dairy products. Oysters are the richest source of zinc, while fruits and vegetables are the poorest. The bioavailability of zinc from plant-based foods is lower due to the presence of phytates [48].

Our experimental data indicate that the zinc content in tomato serum and wheat flour from industrial producers is stable, ranging from 1.921 to 2.685 mg/kg and 8.12 to 9.429 mg/kg, respectively.

The bioavailability of minerals in flour, and consequently the functionality of bread, can be significantly improved by using sourdough, including spontaneous (natural) fermentation [49-54]. Dalia Cizeikiene and co-authors found that the bioavailability of iron, zinc, manganese, calcium, and phosphorus in whole-grain wheat bread could be increased by an average of 30% by using lactic acid bacteria Pediococcus pentosaceus KTU05-8 and KTU05-9 [55].

In addition to the phytase activity of lactic acid bacteria in sourdough, acidifying the dough also stimulates the endogenous phytase in flour, thus improving mineral bioavailability [56]. Since the acidity of analyzed tomato serum samples from different groups (with varying fruit colors) is between 3.90 and 4.37 pH units, incorporating it into dough will also contribute to increased mineral bioavailability.

The use of bakery sourdoughs also promotes the "healthiness" of baked goods by lowering their glycemic index, reducing gluten content, and stimulating the development of a healthy gut microbiota [49, 50, 53, 54, 57].

From a microbiological perspective, sourdough represents a specific ecosystem characterized by an acidic environment and a higher concentration of lactic acid bacteria compared to yeasts (the ratio can range from 10:1 to 100:1) [53]. Common lactic acid bacteria in spontaneous (natural) fermentation sourdoughs include F. sanfranciscensis, L. brevis, L. fermentum, L. plantarum, Pediococcus pentosaceus, Companilactobacillus paralimentarius, Limosilactobacillus reuteri [58-60], and yeasts from the genera Saccharomyces and Kazachstania [61].

For sourdough to be active and exhibit its properties fully, favorable conditions for the microorganisms involved must be created. Improving the biotechnological characteristics of sourdough by stimulating the activity of fermentative and acid-producing microorganisms contributes to producing products with enhanced organoleptic properties (appearance, taste, smell, crumb texture).

The main source of nutrition for sourdough microorganisms is fermentable carbohydrates in the starch fraction of flour (substrate). Wheat flour is estimated to contain 0.2% to 2.0% fermentable sugars, including glucose, fructose, maltose, sucrose, raffinose [62]. Yeasts and lactic acid bacteria have high vitamin and growth stimulant needs. Adding B vitamins to the medium increases the number of viable cells [63].

To ensure growth and development, yeast cells require several inorganic compounds – phosphorus, magnesium, small amounts of iron and copper, and trace elements such as iodine, boron, cobalt, manganese, and tin. Phosphate, potassium and magnesium play an important role in yeast-growth, esters and higher alcohols formation; and short chain fatty acid reduction; ethanol formation is Mg-dependent [64]. For lactic acid bacteria, manganese is particularly important as it prevents cell autolysis and supports normal lipid metabolism, while copper, iron, sodium, potassium, phosphorus, iodine, sulfur, and magnesium are also essential. Among macroelements, phosphorus, potassium, sodium, magnesium, and calcium are most important for yeast cell viability [65].

Increasing the concentration of Mn^{2+} ions in the medium leads to more active sugar fermentation by intensifying glycolytic processes, resulting in a higher final concentration of lactic acid. However, elevated Mn^{2+} ion concentrations can negatively affect saccharification [66]. Several studies on the metabolism of Lactobacillus bacteria confirm the trend of increased lactic acid concentrations with higher manganese salt concentrations [67-68].

Mineral salts in yeast cells are necessary for regulating osmotic pressure, activating enzyme systems, regulating pH, and oxidative-reduction potential [65].

Thus, tomato serum, which contains a broad range of macro- and microelements (Table 3, 4), can be effectively used in the technology of bakery sourdoughs and yeast-leavened baked goods, including functional products. Moreover, tomato serum could be valuable not only to the bakery industry but also to the pasta industry, beverage production (including both non-alcoholic and alcoholic drinks) [69], as well as in the production of brine for meat semi-finished products and vegetable preserves.

CONCLUSION

The novelty of the presented research lies in obtaining experimental data on the elemental composition of tomato serum, which allows for an assessment of its potential use in the production of food products, including functional foods.

Based on the experimental data obtained:

- The dry matter content in the tomato serum ranges from 4.8% to 6.1%, primarily comprising carbohydrates, organic, phenolic, and polyphenolic compounds, water-soluble vitamins, macro- and microelements.
- All tomato serum samples had an acidic reaction: the "Sibirskiy Skorospeliy" variety was the acidic at pH 3.90, "Chernyy Aysberg" had a pH of 3.99, and "Zolotoye Runo" was the least acidic at pH 4.37.
- The content of 24 mineral elements was determined in both tomato serum and premium-grade wheat flour. Tomato serum from various tomato varieties contains a broad range of minerals. Potassium is the most abundant (2,755.5-3,274.5 mg/kg), with its content being 1.3-2.1 times higher than in premium-grade wheat flour. Significant amounts of phosphorus (275.8-279.0 mg/kg), magnesium (116.3-146.4 mg/kg), and calcium (63.88-91.61 mg/kg) are also present in the serum. Iron content varies from 2.533 mg/kg (variety "Chernyy Aysberg") to 17.630 mg/kg (variety "Sibirskiy Skorospeliy"). In premium-grade wheat flour from JSC "Mukomolny Kombinat 'Voronezhskiy'" and JSC "Makfa," iron content is 9.109-9.643 mg/kg, while in the sample from LLC "Chernyy Khleb," it is 2.29-2.43 times higher. Zinc content in tomato serum and industrial wheat flour ranges from 1.921-2.685 mg/kg and 8.12-9.429 mg/kg, respectively. Consuming 100 g of tomato serum can satisfy 7.9-9.4% of the daily potassium requirement, 2.8-3.5% of magnesium, 4.7-9.8% of iron, and 3.9-4.0% of phosphorus. Sodium content in tomato serum is minimal, ranging from 23.74 to 68.11 mg/kg, which corresponds to 0.2-0.5% of the daily requirement for an adult.
- In the wheat flour sample from LLC "Chernyy Khleb," the content of elements such as aluminum, calcium, chromium, copper, potassium, lithium, magnesium, manganese, sodium, nickel, lead, selenium, vanadium, and zinc are significantly higher compared to other flour samples.
- Tomato serum is a valuable ingredient that can enrich the mineral composition of bakery products, improve the bioavailability of minerals in flour, and enhance the biotechnological properties of baker's sourdoughs, thereby increasing their functionality.

- Tomato serum, which contains a wide range of macro- and microelements, can be successfully used in bakery technology. A specific application could be as a growth stimulator for wheat sourdough microorganisms (including type 1, I). This is an effective method for improving the biotechnological properties of baker's sourdoughs and, consequently, enhancing their functionality while improving the organoleptic and physio-chemical quality indicators of bakery products, including enriched and functional products.

Thus, due to the presence of a wide range of minerals, primarily potassium, calcium, magnesium, phosphorus, and iron, tomato serum can serve as a source of these elements in the creation of various food products, including functional foods aimed at the prevention of cardiovascular diseases [70-74].

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List of Abbreviations: DNA, Deoxyribonucleic Acid; TR CU, Technical Regulation of the Customs Union

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Authors' contributions: IZ: discussed the idea of studying the content of chemical elements in tomatoes serum depending on the color of the fruit and in wheat flour and developed the study design, provided the collection of tomato fruit samples for the study, and edited and finalized the manuscript for submission; IP: discussed the idea of studying the content of chemical elements in tomatoes serum depending on the color of the fruit and in wheat flour and developed the study design, provided the collection of tomato fruit samples for the study; GM: discussed the idea and developed the study design, edited and finalized the manuscript for submission; DI: provided the collection of tomato fruit samples for the study, provided the experimental part of the work and systematized the data and analyzed the results.

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