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Development and physicochemical evaluation of a lycopene-enriched additive based on tomato and watermelon powders

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ABSTRACT

Tomato and watermelon powders are promising sources of functional ingredients containing lycopene, citrulline, vitamins, and minerals. Due to their antioxidant, anti-inflammatory, and cardioprotective properties, they are considered valuable for the prevention of cardiovascular and oncological diseases and for supporting general health. Lycopene is recognized as one of the most effective natural antioxidants and is actively studied in the context of chronic disease prevention. The objective of this controlled experimental study was to develop a lycopene-enriched dietary supplement (DS) using local varieties of tomatoes and watermelons, combined with auxiliary ingredients to enhance bioavailability and consumer properties. For lycopene extraction, tomatoes and watermelons were subjected to infrared drying at 50–60 °C until a residual moisture of 10–13 %, followed by hexane extraction (raw material: solvent ratio 1:5) at 40 °C for 45 min. The developed supplement included lycopene, pumpkin seed powder, safflower oil, tomato powder, and watermelon powder. Five formulations were tested, with experimental units randomly allocated to recipes for organoleptic evaluation. Sensory analysis identified the formulation with the ratio 1:3:1:8:7 as the most preferred. This composition was further characterized for its chemical profile, including dietary fiber, ash, protein, fat, carbohydrates, vitamins, water- and fat-soluble antioxidants, and trace elements. The results confirmed that the selected formulation combines high antioxidant potential with balanced nutritional composition and acceptable sensory quality. These findings support the feasibility of producing lycopene-based functional foods and dietary supplements from local plant resources in Kazakhstan, thereby contributing to population health and the development of innovative agri-food technologies. This study was conducted within the framework of the project “Development of technology for the production of biologically active supplements of functional purpose with low cost and high quality indicators for the prevention of oncological diseases” (scientific-technical program BR22886613), funded under budget program 267, subprogram 101, Ministry of Agriculture of the Republic of Kazakhstan (2024–2026).

Keywords: lycopene, tomato powder, watermelon powder, extraction, food additive

INTRODUCTION

In recent years, the natural carotenoid lycopene, a powerful antioxidant, has attracted increasing attention due to its health benefits. Lycopene is a fat-soluble carotenoid that can impart yellow to red hues to foods. It is found in tomatoes, watermelon pulp (3.55-4.86 mg/100 g), red grapefruits, sea buckthorn, and rose hips. Lycopene is registered as a food additive E-160 and is approved for use in Russia, Belarus, the USA, Australia, New Zealand, and the European Union. The recommended daily intake of lycopene is 5-10 mg **[1]**. The main function of lycopene in the human body is antioxidant. Reducing oxidative stress slows down the development of atherosclerosis and provides DNA protection, which can prevent oncogenesis. Consumption of lycopene, as well as lycopene-containing products, leads to a reliable reduction in oxidative stress markers in humans. Lycopene is the most powerful carotenoid - an antioxidant present in human blood **[2]**.

Scientists do not abandon hope that, thanks to their research, they will discover the secret of preserving youth, increasing immunity, reducing the risk of cardiovascular diseases, maintaining normal intercellular metabolism, and reducing the risk of cancer.

Eating tomatoes twice a week, although it cannot completely counteract this, will still reduce the risk of cancer by 34 percent **[3]**. For a long time, the provitamin theory dominated studies of the biological properties of carotenoids, according to which their main role in the human body is the bioconversion of vitamin A. In recent years, experimental data have been obtained indicating that these substances have antioxidant, adaptogenic, anticarcinogenic, radioprotective, antimutagenic and immunomodulatory properties that are not associated with their provitamin activity **[4]**, **[5]**, and **[6]**. The independent role of beta-carotene in the human body has been established, but there is virtually no information on the biological activity of lycopene (a carotenoid that cannot be converted into retinol) **[7]**. Lycopene is a natural carotenoid pigment synthesized by plants and some microorganisms. This food ingredient is not synthesized in the body, but comes with food products. More than 80% of lycopene is obtained from processed tomato products and tomato juice **[8]**. Lycopene plays an important role in suppressing the inflammatory response, and its activity in this direction is primarily associated with the suppression of its main mediators, such as reactive oxygen species (ROS) **[9]**. The biological activity of lycopene is due to its anticarcinogenic, immunomodulatory, cardioprotective, antiatherogenic, radio- and photoprotective effects **[10]**. The significant role of lycopene in preventing chronic cardiovascular diseases has been proven, especially under conditions of high oxidative stress in smokers **[11]**. Priority food sources are red tomatoes and tomato-containing products, which have high levels of lycopene (tomato paste - 28.8 mg / 100 g, tomato puree - 21.8 mg / 100 g, tomato sauces - 12.1-18.9 mg / 100 g, tomato juice - 9 mg / 100 g) **[12]**. Compared to fresh tomatoes, which contain 2.7 mg/100 g of lycopene, higher levels are found in chopped canned tomatoes – 5.1 mg/100 g, and tomatoes prepared in various ways (frying, stewing, baking) – 3 mg/100 g **[13]**.

In addition to tomatoes, there are additional sources of lycopene: guava (5.2 mg/100 g), watermelon (4.5 mg/100 g), papaya (1.8 mg/100 g), pink and red grapefruits (1.4 mg/100 g) **[14]**. In most regions, tomato-containing products are a source of lycopene, but they are presented in diets in different forms. In the southeastern United States, lycopene intake is due to the presence of pizza and pasta in the diet **[15]**, in the UK and France – fresh and canned tomatoes and pizza, in the Netherlands and Ireland – fresh tomatoes, tomato soups and pizza, in Spain – fresh tomatoes and tomato puree **[16]**, in Belgium – fresh tomatoes, tomato-containing products and tomato sauces in ready-to-eat dishes **[17]**.

All over the world, researchers are working to determine the optimal drying conditions that allow for the preservation of the maximum amount of lycopene and other biologically active substances.

However, despite numerous studies, certain difficulties and problems remain associated with the technology of obtaining lycopene from tomato and watermelon extracts. One of the limitations is the high sensitivity of lycopene to heat, which leads to its loss during the drying process. In addition, the development of optimal drying technologies that allow preserving the maximum amount of biologically active properties of lycopene requires additional research and process optimization **[18]**, and **[19]**.

The study's objects were powders from tomatoes and watermelons, dried by infrared drying to a residual moisture content of no more than 13%. The choice of tomato powder as a functional ingredient for developing a dietary supplement is due to several reasons. Designing technological lines for the production of food powders from vegetable raw materials and secondary products of juice production based on agricultural and processing enterprises of our Republic of Kazakhstan will, in the future, solve the problem of creating waste-free food production, since secondary resources generated during the processing of tomatoes are valuable raw materials for the production of food additives. Tomatoes have a unique chemical composition, which varies slightly depending on the variety, the place of fruit growth, and the cultivation technology **[20]**. They include macronutrients in an easily accessible form, an average of 16.5 g of dietary fiber **[21]**. Protein substances of tomatoes contain all essential amino acids, a large amount of glycine, proline, serine, etc. The composition of fats includes omega-3 and omega-6 fatty acids. Potassium, calcium, magnesium, sodium, phosphorus, iron, manganese, as well as copper, selenium, and zinc compounds are registered in significant quantities in vegetables. Tomatoes are a rich source of vitamins, including almost all the B vitamins, vitamin C, vitamin A, vitamin E, vitamin K, and carotenoids. Among the latter compounds, a large amount is lycopene, which not only determines the attractive red color of tomato powder but also confers powerful antioxidant properties. The content of food acids in tomatoes is on average 0.5%, and dietary fiber is 0.8%, and pectin substances account for 0.3%. It should be noted that in terms of vitamin E, nicotinic and pantothenic acids, these substances are leaders among vegetable additives, and the increased content of pectin substances in tomatoes helps to reduce cholesterol in the blood **[22]**. The fruits are considered good antidepressants, and due to their high serotonin content, they help regulate the nervous system's functioning. Additionally, tomatoes possess antibacterial and anti-inflammatory properties **[23]**. Tomato powder also includes all of the above compounds, is an excellent flavoring agent, and natural dye. It gives products a sour taste, a pronounced tomato smell and a fiery color. It is used to prepare first and second courses, sauces, salads, marinades, sautés, pizza, and appetizers. It goes well with meat, vegetables, herbs (dill, parsley, basil), sour cream and beans. It is often used as a decoration for ready-made dishes. Original spice mixtures can be produced based on tomato powder **[24]**, and **[25]**. Tomato and watermelon powders, as well as supplements based on these products, are effective means of maintaining human health due to their biologically active components, such as lycopene, citrulline, vitamins, and minerals. These powders and supplements possess antioxidant, anti-inflammatory, and cardioprotective properties, making them beneficial in preventing various diseases, including cardiovascular disease and cancer, while also maintaining normal hydration levels and promoting overall health. Lycopene, found in tomatoes and watermelon, is one of the most powerful antioxidants that has been extensively studied for its role in preventing chronic diseases. Tomato powder is a concentrated form of tomatoes that retains all of the essential nutrients, including lycopene, B vitamins, vitamin C, and minerals such as potassium. Tomato powder is widely used as a health supplement because it contains high levels of lycopene, which is a carotenoid with strong antioxidant properties. When lycopene enters the body, it neutralizes free radicals that damage cells and contribute to inflammation and disease. Research shows that lycopene can reduce the risk of cardiovascular disease and may also play a role in preventing cancer, particularly prostate, breast and stomach cancer. Regular consumption of tomato powder can reduce oxidative stress and have a protective effect on blood vessels, preventing the development of atherosclerosis and other vascular diseases **[26]**. Watermelon powder, like tomato powder, is a concentrated form of the corresponding fruit, which retains all the beneficial substances, including lycopene, vitamins C and A, and the amino acid citrulline. Citrulline is a key component that helps improve blood circulation, dilate blood vessels, and lower blood pressure. This makes watermelon powder beneficial for individuals with hypertension and other cardiovascular diseases.Watermelon powder also helps to normalize the water-salt balance, improve hydration and can be helpful for people engaged in intense physical activity. Unlike tomato powder, watermelon powder contains less lycopene, but is still a valuable source of this antioxidant, which confirms its ability to reduce inflammation and oxidative stress in the body **[27]**.

Tomato- and watermelon-based dietary supplements have gained popularity due to their numerous beneficial properties. Tomato nutritional supplements, as a rule, contain lycopene concentrates obtained from tomato powder and are actively used to maintain heart health, prevent cancer, and improve skin condition. Lycopene in such supplements has a powerful antioxidant effect, reduces lipid oxidation, improves vascular health, and reduces the risk of atherosclerosis and hypertension.

Watermelon dietary supplements containing watermelon powder extracts have similar antioxidant and vasodilatory properties. The primary active ingredient in these supplements is citrulline, which helps dilate blood vessels and enhance blood circulation. Watermelon supplements are beneficial for individuals with hypertension, as they aid in lowering blood pressure and improving microcirculation. Citrulline, turning into arginine in the body, activates the synthesis of nitric oxide, which helps to relax and dilate blood vessels, improving blood flow and reducing pressure. This property makes watermelon supplements useful not only for individuals with hypertension, but also for those seeking to enhance athletic performance, as they help better supply muscles with oxygen and nutrients during physical activity **[28]**. Tomato and watermelon powders used as dietary supplements are becoming an important tool for maintaining health, strengthening the immune system, reducing the risk of chronic diseases and improving the overall condition of the body. These supplements can be beneficial in both preventing and treating various diseases. The benefits of their consumption are supported by numerous scientific studies, which show that regular consumption of tomato and watermelon supplements can significantly improve the quality of life and maintain high levels of health.

Scientific Hypothesis

The use of local varieties of watermelon and tomato as sources of lycopene, supplemented with additional ingredients, will enable the creation of a biologically active supplement with high antioxidant potential.

Objectives

Primary objectives: This study aimed to develop a biologically active supplement (BAS) based on lycopene obtained from tomato and watermelon powders, evaluate its physicochemical characteristics and organoleptic properties, and determine the most preferred formulation option that is potentially suitable for use as a functional food product.

MATERIAL AND METHODS

The research was conducted at the Kazakh Research Institute of Processing and Food Industry of the Ministry of Agriculture of the Republic of Kazakhstan, in the Laboratory of Technology for Processing and Storage of Plant Products.

Samples

Samples description: The study used domestic varieties of watermelons Asar and tomatoes Solnechny, distinguished by a high content of carotenoids, primarily lycopene. The content of lycopene was determined by the method of dehydration with hexane, and analyses were also carried out to determine the mineral, amino acid, and chemical composition of the pulp of tomatoes and watermelons.

Samples collection: Tomatoes and watermelons were purchased from a local market in Almaty, Kazakhstan. The raw materials were stored in a refrigerator at 2 °C to 4 °C.

Samples preparation: To obtain the powders, tomatoes and watermelons were washed, inedible parts were removed, and they were cut: tomatoes into slices, watermelons into pieces weighing 0.01–0.03 kg. The samples were placed on trays in one layer and subjected to infrared drying. Three temperature modes were studied: 50 °C and 60 °C until a residual moisture content of 10–13% was achieved. After that, the samples were ground into powder.

Number of samples analysed: 5 prescription options for a dietary supplement developed based on lycopene from tomato and watermelon powders.

Chemicals

In this study, n-hexane of chemical purity 99%, manufactured in China, was used as an organic solvent.

Animals, Plants and Biological Materials

Watermelon and tomatoes, pumpkin seeds, and safflower oil were used in this study. Animals and biological materials were not used in this study.

Instruments

The following instruments were used in the study: Basic Station 3 infrared dryer (InfraTec GmbH, Germany), Daihan Scientific convection dryer (South Korea), PD-400 disk mill (Russia), Analysette 3 Pro vibrating sieve analyzer (FRITSCH GmbH, Germany), A11 Basic analytical mill (IKA-Werke GmbH, Germany), AND MX-50 moisture meter (A&D Company, Japan), AquaLab 4TE water activity meter (METER Group, USA), Series 300 food analyzer (FOSS Analytical, Denmark), Prominence LC-20 HPLC system (Shimadzu Corporation, Japan), RV 3 eco rotary evaporator (IKA-Werke GmbH, Germany), Sonopuls HD 3200 ultrasonic homogenizer (Bandelin Electronic, Germany).

Laboratory Methods

Lycopene extraction. Lycopene was extracted from pre-prepared tomato and watermelon powders using hexane 99% (analytical grade, China) at a raw material: solvent ratio of 1:5, temperature 40 °C, and duration 40 min. Ultrasound treatment was performed with a Bandelin Sonopuls HD 3200 homogenizer. After extraction, the mixture was separated by vacuum filtration, and the solvent was removed using a rotary evaporator RV 3 eco (IKA, Germany).

HPLC verification. Lycopene quantification was verified by high-performance liquid chromatography (HPLC). Tomato extracts were prepared as described above, evaporated to dryness, redissolved in 1 ml acetonitrile, and filtered through PTFE syringe filters (0.45 µm). Chromatographic separation was performed using a Shimadzu Prominence LC-20 system (Shimadzu, Kyoto, Japan) equipped with a binary pump (LC-20AD), autosampler (SIL-20AC), degasser (DGU-20A5), column thermostat (CTO-20A), and UV detector (SPD-20A), controlled by LCSolution v.1.25 SP1 software. Separation was performed on a Thermo Hypersil GOLD C18 column (150 × 4 mm, 5 µm) at 30 °C; Mobile phase: acetonitrile (100%); Flow rate: 0.8 ml/min; Injection volume: 20 µl; Detection wavelength: 472 nm **[30]**. Lycopene standards (5 and 10 µg/ml) were prepared by serial dilution from a 20 µg/ml stock solution and filtered through PTFE syringe filters (0.45 µm) before injection.

Analytical methods. Ash content was determined according to GOST R 53642-2009. Magnesium and calcium content was determined according to GOST EN 15505-2013. Phosphorus content was determined according to GOST R 51482-99 (ISO 13730-96). Heavy metals (copper, iron, lead, cadmium) were determined according to GOST 26931-86, GOST 26928-86, GOST 26932-86, and GOST 26933-86. Moisture content was determined according to GOST 13586.5-2015 and GOST 24027.2-80. Titratable acidity was determined according to GOST 27493-87. Fat content was determined according to GOST 23042-86. Protein content was determined according to GOST 25011-81 and GOST R 50453-92 (ISO 937-78).

Description of the Experiment

Study flow: The study included obtaining tomato and watermelon powders, their extraction and subsequent analysis. Lycopene extraction was performed using hexane at 40 °C for 40 min, the raw material:solvent ratio was 1:5. Ultrasonic treatment was used to improve efficiency. The resulting extracts were purified from the solvent and analyzed for a range of physicochemical parameters: ash content, moisture, acidity, protein content, fat, macro- and microelements, and heavy metals. Lycopene content was confirmed by HPLC using standard calibration solutions.

Based on the raw materials and extracts, 5 formulations of a dietary supplement with different component ratios (lycopene, tomato powder, watermelon powder, pumpkin seed powder, safflower oil) were developed. All

5 samples were subjected to organoleptic evaluation by 10 adult tasters on a 5-point scale for such characteristics as taste and smell. For each additive variant, the analysis was carried out in 3 parallel replicates. Based on the data obtained, the most preferable formulation was selected, which was then examined for an extended set of characteristics: the content of vitamins, fiber, and antioxidant compounds.

Quality Assurance

Number of repeated analyses: Each analysis had a threefold repeatability.

Number of experiment replication: Each experiment was conducted three times.

Reference materials: Lycopene standards prepared by serial dilution (5 and 10 µg/mL) from a 20 µg/mL stock solution in acetonitrile were used for calibration and verification of HPLC results. Method validation was performed by comparing retention time and spectral characteristics of lycopene at 472 nm. For determination of ash, protein, fat, moisture, acidity, minerals, and heavy metals, official GOST and ISO procedures were applied (GOST R 53642-2009; GOST EN 15505-2013; GOST R 51482-99 / ISO 13730-96; GOST 26931-86, 26928-86, 26932-86, 26933-86; GOST 13586.5-2015; GOST 24027.2-80; GOST 27493-87; GOST 25011-81; GOST R 50453-92 / ISO 937-78; GOST 23042-86; GOST ISO 7218-2015). These standards served as the primary reference framework for method accuracy and reliability.

Calibration: Analytical balances were calibrated daily with certified calibration weights according to internal laboratory procedures. The moisture analyzer (AND MX-50) was calibrated using reference samples of known water content in accordance with GOST 8.586.1-2005. The HPLC system (Shimadzu Prominence LC-20) was calibrated with prepared lycopene standard solutions (5 and 10 µg/mL); calibration curves were constructed with linearity $R^2 > 0.99$. The UV detector wavelength was verified at 472 nm against the lycopene absorption maximum. The rotary evaporator (IKA RV 3 eco) was checked for temperature and vacuum accuracy with internal reference instruments. The ultrasonic homogenizer (Bandelin Sonopuls HD 3200) was validated for amplitude and frequency stability before each use.

Laboratory accreditation: The experiments were conducted in the laboratory accredited bythe accreditation system of the Republic of Kazakhstan for compliance with the requirements of GOST ISO/IEC 17025-2019

Data Access

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Statistical Analysis

Statistical data processing was performed using the Statistica 14.0 software package (StatSoft Inc., USA). Variance statistics were used for evaluation. Nonparametric methods were used (Wilcoxon-Mann-Whitney test). The arithmetic mean and standard error of the mean (M ± SE) were determined. For data presentation in tables, results are expressed as mean ± standard deviation (SD). Differences were considered statistically significant at $p < 0.05$. Each analysis was performed in triplicate, and all experiments were repeated three times to ensure the accuracy, consistency, and reproducibility of the results.

RESULTS AND DISCUSSION

As a result of the conducted studies, experimental data were obtained reflecting the influence of temperature and time modes of infrared drying on the physicochemical and organoleptic characteristics of the obtained powders and extracts. The results of the experiment are shown in Table 1.

Table 1 Organoleptic and physicochemical properties of watermelon and tomato powders.

Name of the indicator	Powders under study	
	Watermelon powder	Tomato powder
Taste and smell	sweet with a distinct watermelon flavor and pleasant aroma	not sweet, with a distinct tomato flavor, sourness, and pleasant aroma
Color	light orange-red, bright red	light red, bright intense red
Consistency	powdery	5.5 ±3.0
Moisture, %	13.1 ± 0.12	13.4 ± 0.15
Titratable acidity, ^{0} T	0.46 ± 0.02	0.38 ± 0.01
Active acidity, units	5.1 ± 0.05	4.3 ± 0.04

Note: ± –standard deviation, statistically significant differences were found using the Wilcoxon/Mann–Whitney test at $p < 0.05$.

The primary advantage of infrared drying is that it enables the rapid and efficient extraction of moisture from materials without significant loss of nutrients, which is crucial when handling biologically active substances. The principle of infrared drying is that infrared radiation penetrates deep into the material, heating it from the inside, which facilitates rapid removal of moisture **[31]**. Unlike traditional methods, where heat is transferred through the air, infrared radiation directly affects the product itself, thereby accelerating the drying process and reducing the risk of thermal degradation of active components, such as vitamin C, lycopene, and other antioxidants **[32]**.

Watermelon powder **Tomato powder**

Figure 1 Appearance of watermelon and tomato powders obtained by infrared drying.

After obtaining dry tomato and watermelon powders by infrared drying, a solvent (hexane) was added to extract lycopene. The solvent for lycopene extraction was selected based on its polarity and the efficiency of lycopene extraction **[33]**. Hexane (reagent grade) was used as a solvent. Extraction was carried out at a ratio of tomato and watermelon powders to solvent of 1:5, at 40 °C and 45 min, which ensured the maximum yield of lycopene - 1580.4 mg / 100 g in tomato powder and 1274.8 mg / 100 g in watermelon. The resulting extract was subjected to freeze drying, involving primary sublimation drying at -40 °C and subsequent desorption at -55 °C for 23 hours, to achieve a residual moisture content of 15% (Figure 2).

A **B** **C** **D**

Figure 2 The process of obtaining lycopene from melons and vegetables.
Note: A - solution in a rotary evaporator flask; B - evaporation in a water bath; C - residue after removal of the solvent; D - obtained lycopene.

The obtained results showed that the use of infrared drying in combination with subsequent lycopene extraction ensures high preservation of biologically active compounds. The yield of lycopene from tomato powder (1580.4 mg/100 g) and watermelon powder (1274.8 mg/100 g) is comparable to the values given in the literature. Thus, Zuorro (2020) reported a content of 820–950 mg/100 g with enzymatic hydrolysis **[16]**, Kehili et al. (2017) obtained 1100–1400 mg/100 g with supercritical CO_2 extraction **[25]**, and Lisovaya et al. (2024) indicated a range of 1350–1600 mg/100 g in tomato pulp **[29]**. Thus, our data fall within the range of published results, confirming the effectiveness of the chosen method. In terms of stability, infrared drying showed clear advantages over convective drying. Huang et al. (2021) noted significant degradation of carotenoids during hot air drying **[27]**, while Anumudu et al. (2024) demonstrated better preservation of antioxidant activity during infrared processing **[28]**.

A study was conducted to determine the lycopene quality indicators in watermelon and tomato extracts. High-performance liquid chromatography (HPLC) methods were used to quantitatively analyze lycopene.

The results are illustrate the peak distribution and dominance of lycopene in the pigment profiles of the studied samples, as presented in Figures 3 and 4.

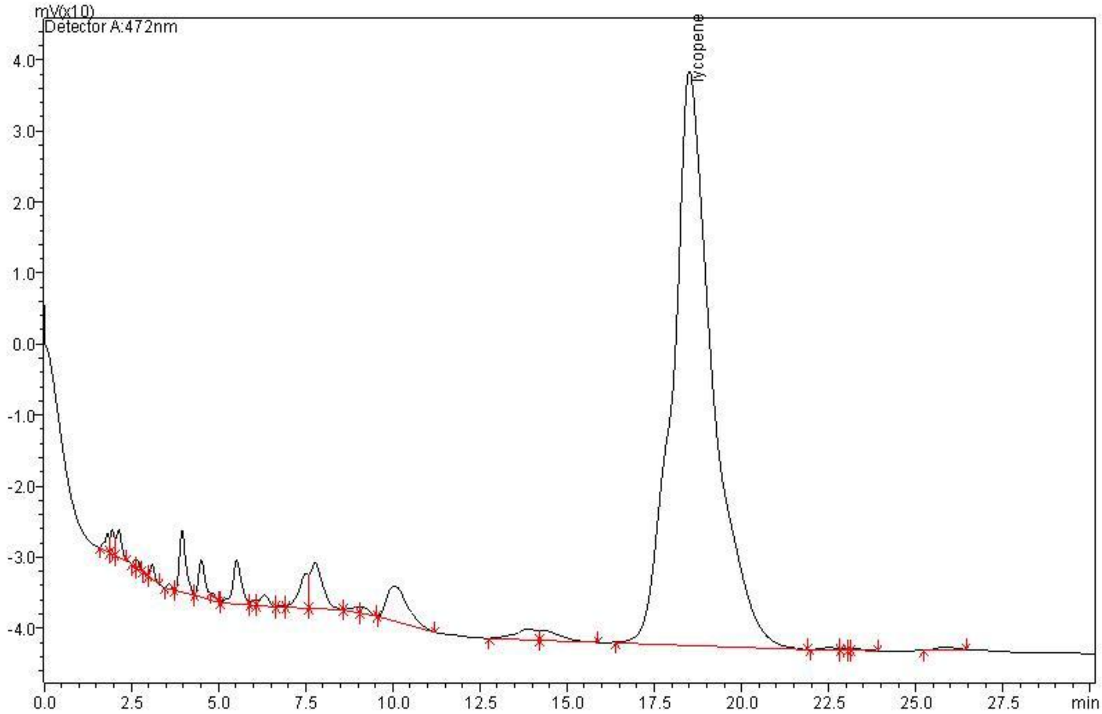

Figure 3 UV chromatogram of hexane extract of lycopene from watermelon.

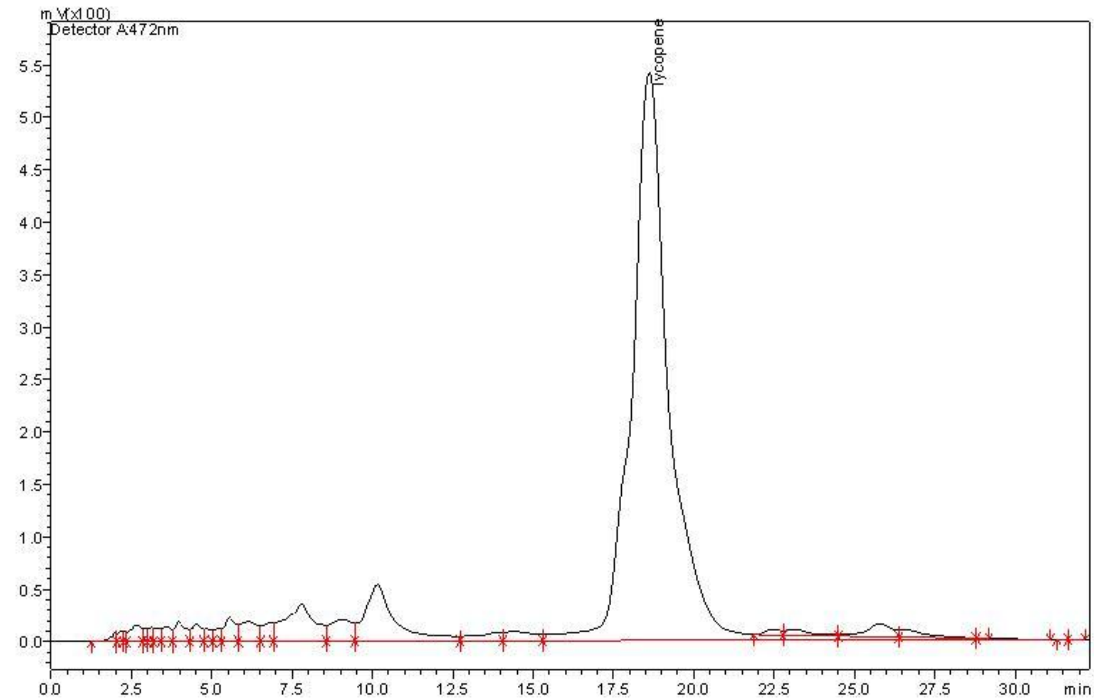

Figure 4 UV chromatogram of hexane extract of lycopene from tomato.

According to the HPLC results, the main pigment of watermelon and tomato extracts is lycopene. In the chromatograms (Figure 3 and Figure 4), its characteristic peak was recorded at a retention time of 18.504 min for watermelon and 18.612 min for tomato. The share of lycopene in the pigment profile was 85.35% in the watermelon extract with a concentration of 25.13 μg/ml and 76.62% in the tomato extract with a concentration of 174.34 μg/ml. The remaining peaks were due to minor compounds that were not identified in this study. The results confirm the dominant role of lycopene in the pigment complex of watermelon and tomato, which determines their color, biochemical profile and the prospects for using these crops as sources of antioxidant carotenoids for the development of functional products. The main active component of the dietary supplement is lycopene, a natural carotenoid known for its ability to neutralize free radicals, reduce oxidative stress, and prevent cell damage. A daily dose of 5 mg is considered effective and safe for maintaining antioxidant activity **[34]**.

A new herbal powdered dietary supplement based on lycopene was prepared by mixing powdered samples of various plants.

As auxiliary components, the supplement includes safflower oil, pumpkin seed powder, as well as watermelon and tomato powders. The supplement in a dosage of 100 mg per serving includes different dosages based on data on physiological needs, bioavailability and organoleptic characteristics of the product:

- The inclusion of lycopene in the amount of 5 g allows for an effective preventive dose of the active substance aimed at reducing oxidative stress and neutralizing free radicals, which is important for preventing the development of oncological processes. This range is selected taking into account the daily requirement for lycopene (5 mg) and its content in the form used, while taking into account the need for joint administration with fats for better absorption;

- The addition of safflower oil in an amount of 5 to 20 mg is aimed at improving the bioavailability of lycopene, since the absorption of carotenoids is significantly increased in the presence of a lipid environment. At the same time, the oil content does not exceed 20 mg, since its excess can negatively affect the taste perception of the product and cause undesirable gastrointestinal reactions **[35]**;

- The introduction of pumpkin seed powder in an amount of 10.0-20.0 mg is justified by its high content of vegetable protein, zinc, magnesium, and phytosterols, which have a mild anti-inflammatory effect and enhance the immune response **[36]**. This component also complements the overall nutrient profile of the dietary supplement and increases its functional focus **[37]**;

- Tomato powder, included in the amount of 25-40 mg, serves as a source of natural lycopene, vitamins C, E, group B and polyphenolic compounds **[38]**. This component helps to enhance the antioxidant activity of the composition, and also gives the product a pleasant taste and color, important for organoleptic perception during long-term use **[39]**;

- Watermelon powder in the amount of 28-40 g enriches the composition with natural sugars, citrulline, lycopene, and vitamins. It also helps to improve the taste characteristics and has a mild vasodilatory and diuretic effect, which has a positive impact on the overall body condition **[40]**.

Thus, a balanced combination of these components within the specified proportions ensures not only high biological activity and targeted preventive focus of the supplement, but also its organoleptic acceptability and functional effectiveness.

The composition of the recipes for the biologically active supplement is developed with consideration for the organoleptic characteristics, including taste and smell, to ensure the acceptability of the dosage form and the stability of its properties under long-term storage conditions. Based on the functional properties of the ingredients and their compatibility, five prescription variants of a biologically active supplement were developed for the prevention of oncological diseases (Table 2). All the developed variants correspond to the daily norm, satisfy organoleptic requirements and include a balanced

Table 2 Composition of prescription versions of biologically active supplements for the prevention of oncological diseases.

Component	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Lycopene, %	5.0	5.0	5.0	5.0	5.0
Pumpkin seed powder, %	20.0	15.0	15.0	15.0	10.0
Safflower oil, %	15.0	5.0	20.0	18.0	20.0
Tomato powder, %	32.0	40.0	30.0	28.0	25.0
Watermelon powder, %	28.0	35.0	30.0	34.0	40.0

To determine the preference of the developed recipes, an organoleptic assessment was carried out on two indicators: taste and smell. Each recipe was assessed on a 5-point scale (where 5 is the highest value, 1 is unsatisfactory). The results are in Table 3.

Table 3 Composition of prescription versions of biologically active supplements for the prevention of oncological diseases.

Name of the indicator	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Taste	3.8 ± 0.4	4.6 ± 0.3	4.4 ± 0.5	1.8 ± 0.2	1.0 ± 0.1
Smell	4.2 ± 0.3	4.5 ± 0.2	4.0 ± 0.4	3.9 ± 0.3	3.8 ± 0.2

Note: ± –standard deviation, statistically significant differences were found using the Wilcoxon/Mann–Whitney test at $p < 0.05$

Data analysis revealed that option 2 exhibited the best organoleptic characteristics, receiving the highest scores for taste (4.6) and smell (4.5). This is due to a successful combination of components, primarily the increased content of tomato powder (40 mg) and the reduced proportion of safflower oil (5 mg), which eliminated the heavy aftertaste and improved the overall perception of the product.

Thus, based on the results of the organoleptic analysis, the second sample of the recipe was selected, which provides the optimal combination of taste and aroma indicators, allowing us to expect an increase in consumer appeal and efficiency of the dietary supplement in further production and use.

The developed formula contains 5.0 mg of lycopene per 100 g of the supplement. At the recommended dosage, this level completely covers the daily physiological requirement (5 mg/day) and does not exceed the upper permissible limit of consumption (10 mg/day) **[41]**. Thus, the proposed dose meets the safety criteria and has a preventive effect on oncological diseases.

The approved composition of the dietary supplement is a balanced combination of components: lycopene (5%) as the main antioxidant; tomato powder (40%), enhancing the antioxidant effect and forming taste characteristics; watermelon powder (35%) with a vasodilating effect; pumpkin seed powder (15%) with immunomodulatory properties; safflower oil (5%) to increase the bioavailability of carotenoids. This composition ensures high efficiency and safety, confirms its potential in the prevention of oncological diseases, and increases consumer appeal.

Figure 5 Appearance of capsules of biologically active supplement.

The study examined the vitamin composition, physicochemical parameters, mineral profile and antioxidant activity of the developed biologically active supplement. The results of the study of the vitamin composition are presented in Table 4.

Table 4 Vitamin composition of the developed biologically active supplement.

Name of indicators, units measurements	Contents in dietary supplements	Daily requirement (mg) [42]
Vitamins, mg/100 g		
B_1	0.322 ± 0.064	1.1-1.4
B_2	1.057 ± 0.445	1.1-1.6
B_3	5.92 ± 3.18	14-18
B_5	2.01 ± 0.40	5-7
B_6	0.966 ± 0.193	1.2-1.7
B_9	0.053 ± 0.011	0.4
C	0.079 ± 0.064	0.075-0.1
A	11.68 ± 0.064	0.7-0.9
E	181.62 ± 0.54	15

Note: ± –standard deviation

The vitamin composition of the studied dietary supplement is characterized by a low content of water- and fat-soluble B vitamins (B1 - 0.322 ± 0.064; B2 - 1.057 ± 0.445; B3 - 5.92 ± 3.18; B5 - 2.01 ± 0.40; B6 - 0.966 ± 0.193; B9 - 0.053 ± 0.011 mg / 100 g), which provides only partial coverage of the physiological need, a minimum level of vitamin C (0.079 ± 0.064 mg / 100 g with a norm of 75-100 mg), but a high content of fat-soluble antioxidants: vitamin A (11.68 ± 0.064 mg / 100 g with a norm of 0.7-0.9 mg) and especially vitamin E (181.62 ± 0.54 mg/100 g with a norm of 15 mg), which determines the pronounced antioxidant properties and the functional focus of the supplement on reducing oxidative stress and preventing diseases.

Table 5 Physicochemical, mineral characteristics of the dietary supplement.

Name of indicators, units of measurement	Value
Moisture, %	7.77 ± 0.06
Ash, %	5.82 ± 0.06
Fiber, %	9.94 ± 0.08
Carbohydrates, %	43.12 ± 0.47
Fat, %	19.35 ± 0.12
Protein, %	13.29 ± 0.14
Acidity, °T	65.4
Fe, mg/100 g	4.04
Mg, mg/100 g	10.36 ± 0.10
Ca, mg/100 g	114.07 ± 2.88
K, mg/100 g	196.14 ± 4.76
Cu, mg/100 g	1055.83 ± 22.64
Zn, mg/100 g	0.594 ± 0.004
Na, mg/100 g	2.91 ± 0.03
Se, mg/100 g	56.10 ± 0.61
P, mg/100 g	0.0064 ± 0.00008
Fe, mg/100 g	249.90 ± 2.74

Note: ± –standard deviation

The physicochemical composition of the dietary supplement is characterized by low moisture (7.77 ± 0.06%) and ash (5.82 ± 0.06%) content, which indicates the stability and concentration of the product, high levels of carbohydrates (43.12 ± 0.47%), fat (19.35 ± 0.12%) and protein (13.29 ± 0.14%), which form its nutritional and energy value, a significant proportion of fiber (9.94 ± 0.08%), providing dietary properties, as well as moderate acidity (65.4 °T) and a pH of 4.04, which indicates an acidic reaction of the environment and contributes to increased microbiological stability of the dietary supplement.

The content of antioxidant compounds in the studied supplement was determined (Table 6).

Table 6 Antioxidant content in the studied dietary supplement

Name of indicators, units of measurement	Value, mg/100 g
Fat-soluble antioxidants	0.62 ± 0.0070
Water-soluble antioxidants	2.08 ± 0.0117

Note: ± –standard deviation

As shown in Table 6, the antioxidant composition of the studied dietary supplement is represented by two groups of compounds: fat-soluble (0.62 ± 0.0070 mg/100 g) and water-soluble (2.08 ± 0.0117 mg/100 g). Fat-soluble antioxidants, mainly tocopherols and carotenoids, function in lipid matrices, preventing peroxidation, while water-soluble compounds, including vitamin C and polyphenols, act in the aqueous phase, blocking free-radical reactions **[43]**. This combination determines the synergistic effect and provides the dietary supplement with high overall antioxidant activity, thereby increasing its functional focus and preventive potential **[44]**.

CONCLUSION

As a result of the work, a biologically active additive (BAA) based on plant raw materials, enriched with lycopene from tomato and watermelon powders, was developed and characterized. To obtain the target compound, the fruits were subjected to infrared drying at a temperature of 50–60 °C, resulting in a residual moisture content of 10–13%. Subsequently, extraction with hexane (raw material:solvent ratio 1:5) was carried out at 40 °C for 45 minutes. This approach ensured a high yield of lycopene — 1580.4 mg/100 g in tomato powder and 1274.8 mg/100 g in watermelon. According to the HPLC results, lycopene was identified as the dominant pigment in the obtained extracts.

Based on the organoleptic assessment of taste and smell, the formula with the following composition was recognized as the most preferable: lycopene - 5%, pumpkin seed powder - 15%, safflower oil - 5%, tomato powder - 40%, and watermelon powder - 35%. The approved version is characterized by a balanced nutrient profile: moisture content was 7.77%, protein - 13.29%, fat - 19.35%, carbohydrates - 43.12%, fiber - 9.94%, ash content - 5.82%. Additionally, the acidity value (65.4 °T) and pH indicate an acidic reaction of the environment and confirm the microbiological stability of the dietary supplement. Vitamin analysis showed low levels of B vitamins (B1 — 0.322 ± 0.064; B2 — 1.057 ± 0.445; B3 — 5.92 ± 3.18; B5 — 2.01 ± 0.40; B6 — 0.966 ± 0.193; B9 — 0.053 ± 0.011 mg/100 g) and vitamin C (0.079 ± 0.064 mg/100 g with the norm of 75–100 mg), but a high content of vitamin A (11.68 ± 0.064 mg/100 g) and especially vitamin E (181.62 ± 0.54 mg/100 g). Vitamin E acts as an additional antioxidant, enhancing the effect of lycopene, which contributes to the supplement's pronounced antioxidant properties. The mineral profile was characterized by a high content of potassium (1055.83 ± 22.64 mg/100 g), calcium (196.14 ± 4.76 mg/100 g) and magnesium (114.07 ± 2.88 mg/100 g), as well as the presence of zinc (2.91 ± 0.03 mg/100 g), copper (0.594 ± 0.004 mg/100 g) and selenium (0.0064 ± 0.00008 mg/100 g).

The content of antioxidant compounds was determined: fat-soluble antioxidants amounted to 0.62 ± 0.0070 mg/100 g, water-soluble - 2.08 ± 0.0117 mg/100 g. This combination provides a synergistic effect and high overall antioxidant activity.

The developed biologically active supplement enriched with lycopene from tomato and watermelon powders exhibited a well-balanced nutrient composition, high concentrations of antioxidants, and favorable organoleptic properties. The applied processing approach ensured both stability and preservation of bioactive compounds, which is particularly relevant for the rational utilization of local plant resources. Comprehensive characterization confirmed the technological feasibility and safety of the formulation. At the same time, the combination of lycopene with natural carriers such as pumpkin seed powder and safflower oil enhanced its functional orientation toward reducing oxidative stress. These results indicate not only the potential of the supplement as a preventive dietary component, but also its applicability for the development of functional foods aimed at lowering the risk of chronic and oncological diseases. The developed technology can be implemented in industrial production for obtaining lycopene-enriched dietary supplements and applied in the development of functional food products with an increased antioxidant content.

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