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Enhancing the content of biologically active components in cluster tomatoes using organic fertilizers

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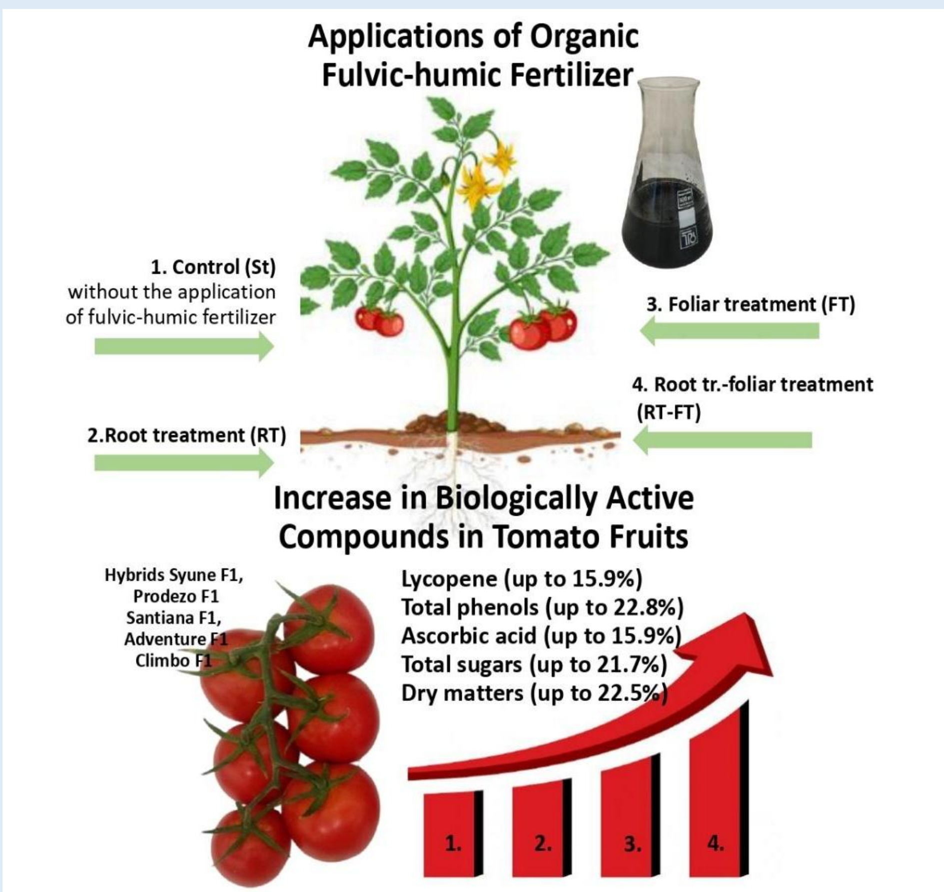
ABSTRACT

Tomatoes *(Solanum lycopersicum L.)* are a vital agricultural crop with significant nutritional value, attributed to their high content of vitamins, minerals, and antioxidants. The antioxidant properties of tomatoes contribute to reducing the risk of cardiovascular and oncological diseases, positioning them as an important component of a balanced diet and beneficial for public health. The application of organic fertilizers containing fulvic and humic acids is particularly relevant to ensure the production of high-quality and nutritious tomatoes. These compounds, recognized as bio stimulants in plant cultivation, enhance physiological processes in plant cells. They stimulate protein and nucleic acid synthesis, activate enzymatic activity, and regulate metabolic pathways, thereby improving the biochemical composition of tomato fruits, increasing their nutritional quality, and enriching the content of bioactive compounds.

The objective of this study is to evaluate the accumulation of bioactive compounds such as lycopene, total phenols, vitamin C, total sugars, and dry matter in cluster tomato fruits using an Armenian fertilizer containing fulvic and humic acids. Additionally, the research aims to provide practical insights into sustainable agriculture by identifying optimal agronomic practices that enhance the accumulation of these bioactive compounds in cluster tomatoes. The research was conducted on greenhouse-grown cluster tomato hybrids: Syune F1 (Armenian breeding), Prodezo F1 (Rijk Zwaan), Santiano F1 (Rijk Zwaan), Adventure F1 (Rijk Zwaan), and Climbo F1 (Syngenta) during the spring growing seasons from the years 2022 to 2024. The experiment utilized an organic fertilizer, and applied by abiding the following treatment scheme: 1. Control (St) — no organic fertilizer application, 2. Root treatment (RT), 3. Foliar treatment (FT), 4. Combined root and foliar treatment (RT-FT). Biochemical analyses of the tomato fruits were performed to quantify lycopene, total phenols, ascorbic acid, and total sugars using spectrophotometry, while dry matter content was determined via refractometry. Statistical data analysis was conducted using analysis of variance (ANOVA).

The study demonstrated that all treatment types with fulvic-humic fertilizer contributed to improving tomato fruit quality and the accumulation of biologically active components. The most effective treatment was the combined root and foliar application (RT-FT), which resulted in the highest values across all measured parameters. Depending on the hybrid, lycopene content increased by 11.1–15.9%, total phenols by 14.7–22.8%, when vitamin C by 13.1–15.9%, total sugars by 13.5–21.7%, and dry matter by 14.6–22.5% compared to the control. The 'Syune' and 'Climbo' hybrids exhibited the highest accumulation of lycopene and phenols, highlighting their potential for enhancing antioxidant properties. The 'Santiana' and 'Adventure' hybrids were notable for their elevated ascorbic acid content, making them particularly valuable for improving nutritional quality. The best results for sugar and dry matter accumulation were observed in the 'Syune' and 'Prodezo' hybrids, indicating improved flavor profiles in these tomato varieties.

Keywords: tomatoes, lycopene, total phenols, ascorbic acids, total sugars, dry matter, organic fertilizer, fulvic acids, humic acids



INTRODUCTION

The quality of tomato fruits *(Solanum lycopersicum L.)* is a key factor determining their nutritional and biological value. Tomatoes are rich in essential micronutrients, including copper, manganese, zinc, and selenium. They are also abundant in natural antioxidants, such as carotenoids (β-carotene and lycopene), ascorbic acid (vitamin C), tocopherol (vitamin E), and phenolic compounds, which collectively contribute to the prevention and management of chronic diseases [1-2].Regular consumption of tomatoes has been shown to strengthen the immune system [3-4], prevent cardiovascular diseases [5-10], reduce the risk of cancer [5, 11-12], and lower the risk of diabetes [13-16].

In response to growing consumer demand for healthier and more eco-friendly agricultural practices, attention has shifted toward sustainable methods that enhance the bioactive compound content of tomatoes, which improves both their antioxidant properties and flavor [17]. One of the promising methods for enhancing fruit quality is the use of organic fertilizers containing fulvic and humic acids. These compounds are widely utilized as biostimulants in agriculture due to their ability to activate essential physiological processes at the cellular level [18]. Their chelating properties improve the absorption of nutrients by plants [19-22], enhance protein and nucleic acid synthesis, and regulate enzymatic activity and metabolism [23], lead to the stimulation of root system growth [24], improve photosynthetic processes, and increase overall plant productivity [25]. Fulvic and humic acids also positively influence the biochemical composition of fruits, increasing the concentration of vital bioactive components such as lycopene, sugars, and vitamins [26].

Nevertheless, the impact of local organic fertilizers on the biochemical parameters of tomato fruits remains insufficiently studied, highlighting the need for further research in this area.

The objective of this study is to investigate the effects of Armenian fertilizer containing fulvic and humic acids on the quality characteristics of tomato fruits. Additionally, the research aims to identify optimal agronomic conditions that promote the maximum accumulation of biologically valuable components in tomato fruits.

The quality of tomato fruits (Solanum lycopersicum L.) is a key factor determining their nutritional and biological value. Tomatoes are rich in essential micronutrients, including copper, manganese, zinc, and selenium. Due to their high concentration of natural antioxidants, such as carotenoids (β-carotene and lycopene), ascorbic acid (vitamin C), tocopherol (vitamin E), and bioactive phenolic compounds, tomatoes can alleviate many health conditions, particularly chronic diseases [1-2]. Regular consumption of tomatoes has been shown to strengthen the immune system [3-4], prevent cardiovascular diseases [5-10], reduce the risk of cancer [5, 11-12], and lower the risk of diabetes [13-16].

In recent years, there has been increasing attention to the application of eco-friendly methods to enhance the content of bioactive compounds in tomato fruits, which play a crucial role in developing their antioxidant properties and flavor quality [17].

One of the promising methods for enhancing fruit quality is the use of organic fertilizers containing fulvic and humic acids. These compounds are widely utilized as biostimulants in agriculture due to their ability to activate essential physiological processes at the cellular level [18]. Their chelating properties improve the absorption of nutrients by plants [19-22], enhance protein and nucleic acid synthesis, and regulate enzymatic activity and metabolism [23], leading to the stimulation of root system growth [24], improved photosynthetic processes, and increased overall plant productivity [25]. Local organic fertilizers, such as the Armenian product used in this study, are of interest due to their high content of bioactive components and potential for sustainably improving fruit quality. However, specific effects on tomato fruit biochemistry have not been fully explored.

These compounds positively influence the biochemical composition of fruits, thereby enhancing their nutritional value and increasing the content of vital bioactive components such as lycopene, sugars, and vitamins [26]. Nevertheless, the impact of local organic fertilizers on the biochemical parameters of tomato fruits remains insufficiently studied, highlighting the need for further research in this area.

The objective of this study is to examine the effects of an Armenian fertilizer enriched with fulvic and humic acids on the quality characteristics of tomato fruits. Additionally, the research aims to offer practical insights into sustainable agriculture by identifying optimal agronomic practices that maximize the accumulation of biologically valuable components in tomato fruits.

MATERIAL AND METHODS

The research was conducted at the Scientific Center of Vegetable, Melon, and Technical Crops of the Ministry of Economy of Armenia, within the glass greenhouse of the center, during the spring growing cycle from 2022 to 2024. The subjects of the study were selected cluster hybrids of tomatoes: Syune F1 (Armenian selection), Prodezo F1 (Rijk Zwaan), Santiano F1 (RZ), Adventure F1 (RZ), and Climbo F1 (Syngenta). Below is a brief description of the hybrids:

Syune F1	Medium-early cluster greenhouse hybrid characterized by indeterminate plants with robust foliage. The cluster-shaped fruit typically contains 5-6 round-flattened fruits, exhibiting an intense red color, weighing between 150-160 g [27].
Prodezo F1	Medium-early cluster greenhouse hybrid characterized by its indeterminate plant growth. It produces cluster-shaped fruits, typically consisting of 5-6 round-flattened fruits. These fruits are noted for their intense red color and weigh between 160-180g [28].
Santiana F1	Medium-early cluster greenhouse hybrid. Santiana F1 plants are indeterminate and are noted for their high early and total yields. The flat clusters contain 5-6 fruits, each weighing 160-170g and displaying a vibrant red color [28].
Adventure F1	Medium-early indeterminate tomato hybrid known for its high yield and fruit quality. It produces round, red fruits that typically weigh between 140-160 grams [28].
Climbo F1	Medium-early indeterminate tomato hybrid known for its high yield and fruit quality. It typically forms 5-6 fruits per cluster, producing round, red fruits that weigh between 140-160 g [29].

The organic fertilizer was characterized by the following parameters:

Dry matter 20–25%, organic matter (C) on a dry matter (DM) basis 20–30%, fulvic acids (DM) 12.0%, humic acids (DM) 7.0%, total nitrogen N (DM) 2.4%, total phosphorus (P_2O_5) (DM) 2.2%, total potassium (K_2O) (DM) 2.22%, pH 7.0–7.6.

The experiment followed a block-randomized design with three replications.

The experiment incorporated the following treatments with organic fertilizer:

1. Control (St) — This control variant used a complex NPK fertilizer without additional organic fertilizer treatment. In the other treatments, the same mineral fertilizer background was applied, supplemented with the following treatments of fulvic-humic fertilizer:
2. Root treatment (RT);
3. Foliar treatment (FT);
4. Combined root and foliar treatment (RT-FT) comprehensive scheme.

The fertilizer was diluted with water and applied in the following proportions and frequencies: for root feeding — diluted at 1:100, four times during the growing season; for foliar feeding — diluted at 1:150 with an interval of 15 days.

The soil composition at a depth of 20-25 cm included: total nitrogen - 4.3-4.8 mg, phosphorus - 6.5-8.2 mg, and potassium - 16.5-18.5 mg per 100 g of soil. The soil electrical conductivity (EC) ranged from 1.5 to 2.5 $dS \cdot m^{-1}$, with a pH of 7.0-7.5. The temperature in the greenhouse was maintained at 25-28°C during the day and 16-20°C at night. The relative humidity was kept between 60-70%.

Biochemical analyses of tomato fruits were conducted at the Laboratory of Plant Biotechnology, Phytopathology, and Biochemistry of the Scientific Center. Key quality indicators of the fruits were measured, including the content of lycopene, total phenols, ascorbic acid, total sugars, and dry matter.

The lycopene content was determined spectrophotometrically using a Cary 60 UV-Vis spectrophotometer (Agilent Technologies, USA) at a wavelength of 503 nm, with prior extraction using a solvent mixture of hexane, acetone, and ethanol. Results were calculated based on 100 grams of fresh weight (FW) of the sample [30].

The ascorbic acid content was determined spectrophotometrically according to the standard method using 2,4-dinitrophenylhydrazine, followed by measuring the absorbance at a wavelength of 520 nm. The calibration solutions were prepared using L-ascorbic acid (Merck, Germany) [31-32].

The total phenolic compound content was determined using the Folin-Ciocalteu reagent. For total phenolic content, gallic acid (Sigma-Aldrich, USA) was used as the standard, and results were expressed in gallic acid equivalents, per 100 grams of FW of the sample. Spectrophotometric measurements were conducted at a wavelength of 725 nm [33].

The sugar content was measured spectrophotometrically. For total sugars, the optical density of the solution was measured at a wavelength of 490 nm. Calibration solutions were prepared using glucose (Merck, Germany) [34]. The dry matter content in the fruits was assessed using a refractometer.

The experimental data was analyzed statistically using ANOVA to evaluate the significance of treatment effects at a confidence level of $p \le 0.05$. The results are presented as means ± standard deviation (SD) based on three independent experimental replicates.

RESULTS

The research indicated that the lycopene content in the fruits of the cluster tomato hybrids increased with the intensity of organic fertilizer treatment. In the control group (St), the lycopene level in the 'Syune' hybrid was 9.41 mg/100g (FW). Following root treatment, the lycopene content increased to 10.21 mg/100g, while after foliar treatment, it reached 10.40 mg/100g, representing increases of 8.5% and 10.5% compared to the control, respectively. The maximum level was observed in the N4 treatment (combined application), achieving 10.91 mg/100g, which is 15.9% higher than the control (Fig. 1).

For the 'Prodezo' hybrid, the control lycopene content was 7.22 mg/100g. With root and foliar treatments, the lycopene levels were 7.68 mg/100g and 7.97 mg/100g, respectively, reflecting increases of 6.4% and 10.4% compared to the control. The highest values were recorded in the N4 treatment, where the lycopene content reached 8.20 mg/100g, indicating a 13.6% increase over the control.

In the 'Santiana' hybrid, the control group recorded a lycopene content of 7.78 mg/100g. Following root and foliar treatments, the lycopene levels increased to 8.39 mg/100g and 8.51 mg/100 g, respectively, reflecting increases of 7.8% and 9.4% compared to the control. In the N4 treatment, the lycopene content reached 8.78 mg/100g, which is 12.8% higher than the control.

For the 'Adventure' hybrid, the initial lycopene level was 8.30 mg/100g. Root and foliar treatments resulted in lycopene content increasing to 8.87 mg/100g and 8.99 mg/100g, corresponding to increases of 6.8% and 8.3%, respectively. In the N4 treatment, the lycopene content reached 9.22 mg/100g, exceeding the control by 11.1%.

In the 'Climbo' hybrid, the control level was measured at 9.12 mg/100g. Following root and foliar treatments, the lycopene content increased to 9.87 mg/100g and 10.16 mg/100g, reflecting increases of

8.2% and 11.4% compared to the control, respectively. The highest value of 10.45 mg/100g was achieved in the N4 treatment, which represents a 14.6% increase over the control.

All hybrids exhibited superior lycopene content results with foliar treatment compared to root treatment. A clear upward trend in lycopene concentration was observed with increasing treatment intensity in the combined application of root and foliar treatments (RT-FT). Notably, the hybrids 'Syune' and 'Climbo' showed the most significant increases in lycopene content in response to the application of fulvic-humic fertilizers.

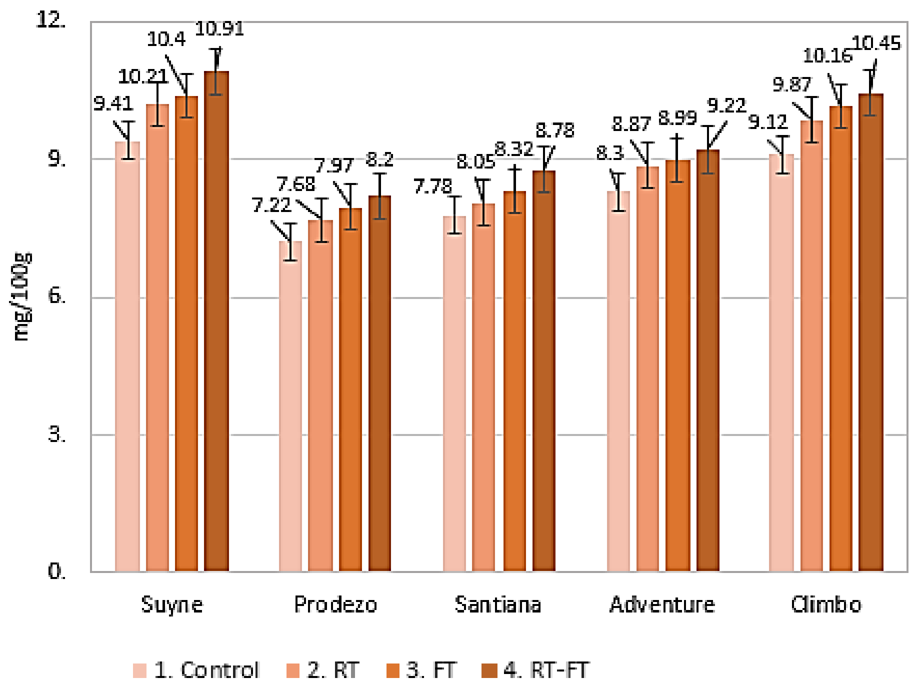


Figure 1. Lycopene content (mg/100 g FW) in the fruits of cluster-type tomato hybrids depending on the type of treatments ($p \leq 0.05$)

Similar trends were observed in the analysis of other parameters, such as with the content of phenols, ascorbic acid, dry matter, and sugars, indicating an overall positive impact of the treatments on the quality of tomato fruits. As with lycopene, the maximum values were attained in treatment N4 (Fig. 2-5).

For the 'Syune' hybrid, the control values were as follows: total phenols – 107.5 mg/100g (FW), ascorbic acid – 22.13 mg/% (FW), total sugars – 3.27% (FW), dry matter – 6.57% (FW). The highest values were recorded in treatment N4: the phenolic content increased to 132.1 mg/100g (+22.8% compared to the control), ascorbic acid rose to 25.03 mg/% (+13.1%), total sugars reached 3.98% (+21.7%), and dry matter increased to 8.05% (+22.5% compared to the control).

For the 'Prodezo' hybrid, the control values were as follows: total phenols – 95.4 mg/100g, ascorbic acid – 20.08 mg/%, total sugars – 3.01%, dry matter – 6.54%. The maximum values were recorded in treatment N4: phenolic content reached 111.7 mg/100g (+17.1%), ascorbic acid increased to 22.89 mg/% (+13.9% above control), total sugar rose to 3.47% (a 15.3% increase), and dry matter reached 7.60% (16.2% higher than the control).

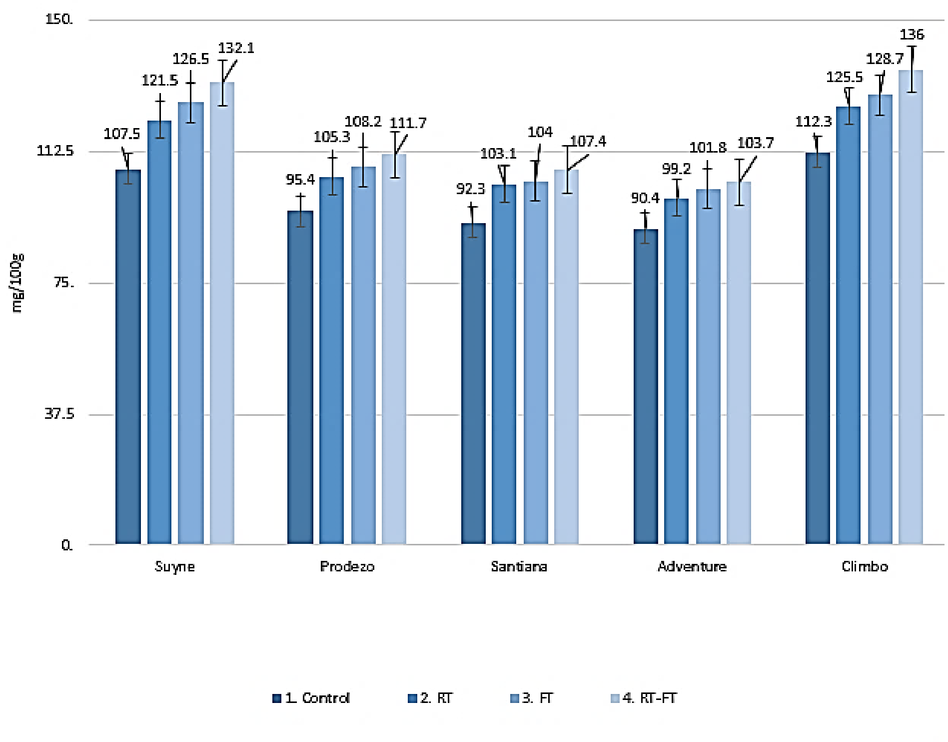


Figure 2. Total phenolic content (mg/100g (FW)) in the fruits of cluster hybrids as affected by treatment types (p ≤ 0.05)

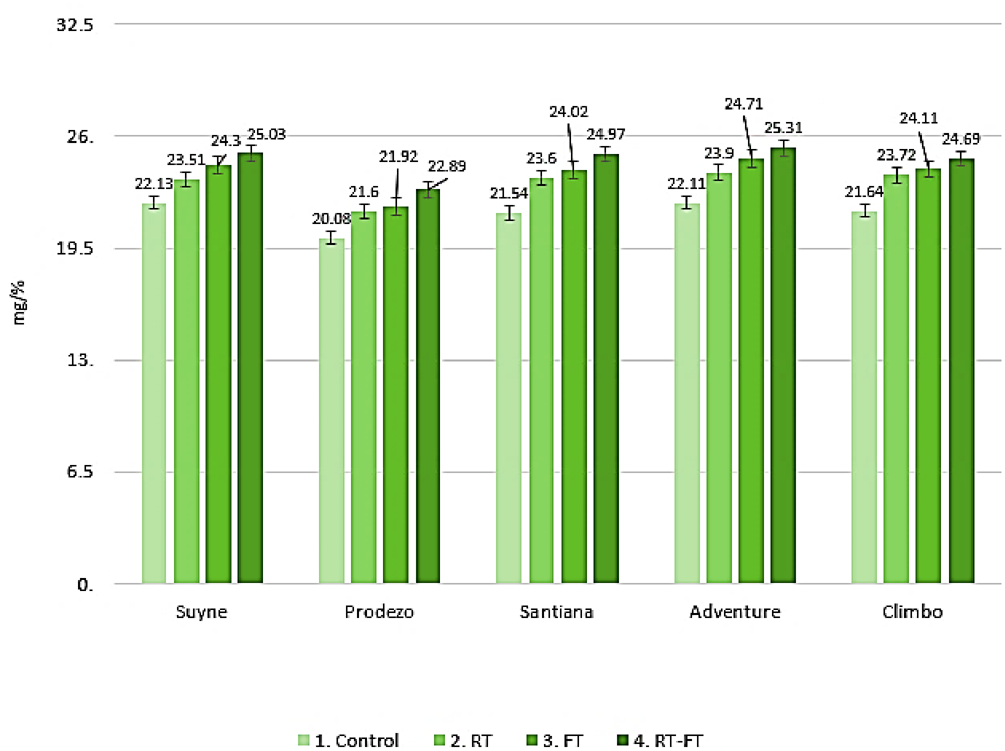


Figure 3. Ascorbic acid content (mg/% (FW)) in the fruits of cluster hybrids is affected by treatment types (p ≤ 0.05)

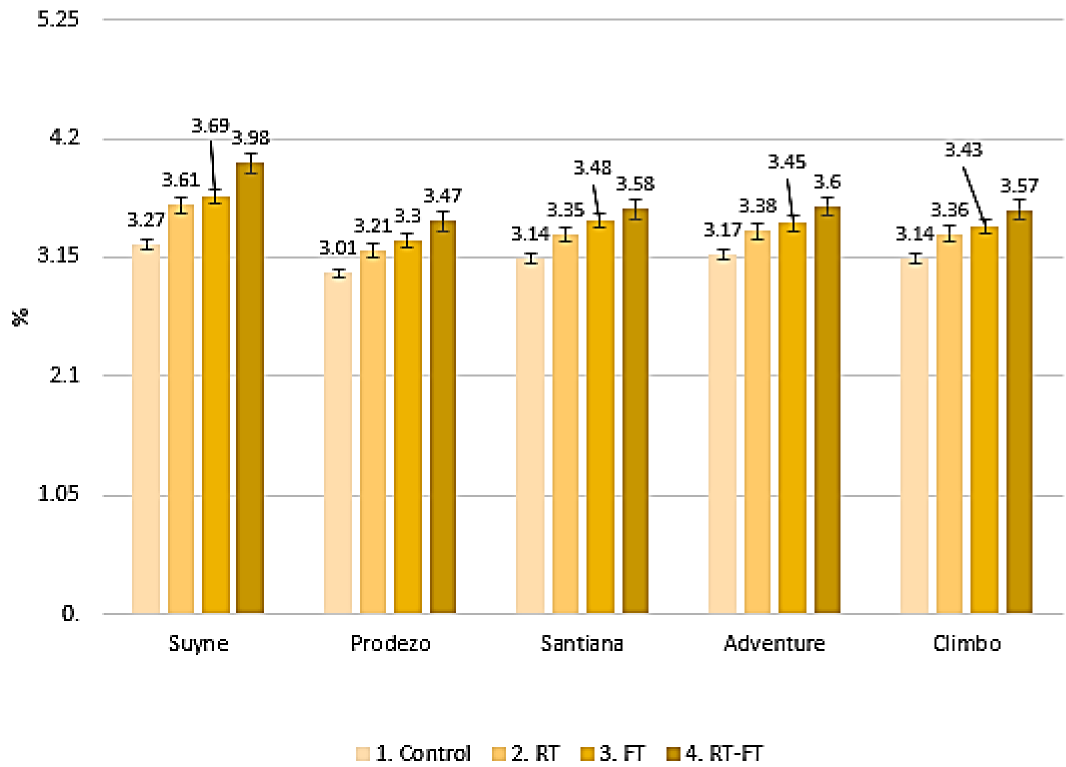


Figure 4. Total sugar content (% (FW)) in the fruits of cluster hybrids as influenced by treatment types ($p \leq 0.05$)

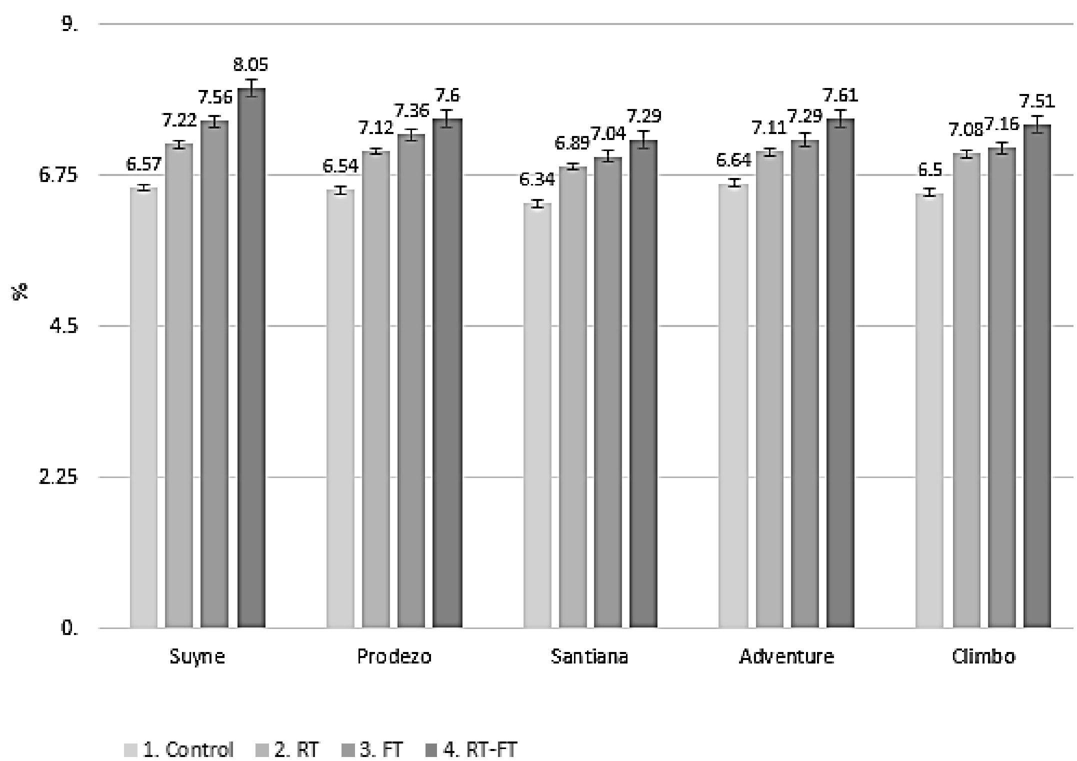


Figure 5. Dry matter content (%) in the fruits of cluster hybrids as influenced by treatment types ($p \leq 0.05$)

For the hybrid 'Santiana', the control values were established as follows: total phenolic content was 92.3 mg/100g, ascorbic acid concentration was 21.54 mg/%, total sugars content was 3.14%, and dry matter constituted 6.34%. Notably, the highest measurements were observed under treatment N4, where phenolic content increased to 107.4 mg/100g, depicting a 16.4% enhancement. Ascorbic acid levels reached 24.97 mg/%, reflecting a 15.9% increase, while sugar content rose to 3.58%, marking a 14.0% augmentation. Additionally, dry matter increased to 7.29%, indicating a 14.9% elevation compared to the control.

In the case of the hybrid 'Adventure,' the control parameters recorded were: total phenols at 90.4 mg/100 g, ascorbic acid at 22.11 mg/%, sugars at 3.17%, and dry matter at 6.64%. The highest values recorded under treatment N4 included phenols at 103.7 mg/100 g, signifying a 14.7% increase, ascorbic acid at 25.31 mg/% (an increase of 14.5%), sugars at 3.60% (a 13.5% rise), and dry matter at 7.61% (a 14.6% increase compared to the control).

For the hybrid 'Climbo,' control measurements indicated a phenolic content of 112.3 mg/100 g, ascorbic acid concentration of 21.64 mg/%, total sugar content of 3.14%, and dry matter of 6.50%. Under treatment N4, the following enhancements were noted: phenolic content reached 136.0 mg/100 g, reflecting a 21.1% increase; ascorbic acid attained 24.69 mg/%, representing a 14.1% increase over the control; sugars amounted to 3.57%, marking a 13.7% elevation; and dry matter rose to 7.51%, a 15.5% increase compared to the control (fig. 2-5).

DISCUSSION

The selection of the tomato hybrids 'Syune,' 'Prodezo,' 'Santiana,' 'Adventure,' and 'Climbo' is driven by the rising market demand in Armenia for cluster tomatoes known for their superior sensory qualities and nutritional benefits. These hybrids exhibit a unique genetic makeup that confers various agronomic advantages. The presence of the rin gene, alongside the genes nor and norA in a heterozygous state, attenuates the ripening process of the fruits, thereby allowing the initial fruits at the base of the cluster to retain structural integrity and remain attached, even as the upper fruits commence ripening. Furthermore, the rin gene facilitates prolonged storage of mature fruits on the vine, preserving their organoleptic and commercial qualities [35].

Moreover, there is a growing demand for eco-friendly and high-quality products from both consumers and farmers. In this context, the selected hybrids play a crucial role as they facilitate the investigation of the effects of organic fertilizers, such as fulvic-humic complexes, on enhancing flavor characteristics, increasing antioxidant levels, and improving the overall quality of the fruits.

To effectively apply fertilizers based on fulvic and humic acids, it is crucial to consider both the dosage and the method of application, as these factors directly influence their efficacy. Research by Khan et al. (2014) [23] has demonstrated that foliar feeding yields positive results, particularly when applied at specific growth stages of the plants. Optimal doses of fulvic acids contribute to enhanced growth, increased chlorophyll content, improved nutrient uptake, and the stimulation of metabolic processes. Exceeding the recommended dosage can impair micronutrient absorption and disrupt balanced plant growth, underscoring the importance of precise dosing.Therefore, experimental studies on the methods of fertilizer application are necessary for each specific case. In our experiment, the best results were achieved through a combined treatment approach that integrated both root and foliar feeding (RT-FT), which demonstrated the most significant impact on the quality of tomato fruits. Conversely, root application exhibited a less pronounced effect compared to foliar application. This finding aligns with other studies that emphasize the importance of foliar feeding in stimulating plant metabolism and enhancing fruit quality [20, 23]. The enhancement of tomato fruit quality is closely linked to the significant effects of fulvic acids (FA) on nutrient absorption and redistribution. The application of FA improves the uptake of phosphorus (P) and potassium (K) in leaves and stems. Concurrently, nitrogen (N) is redistributed from the roots to the fruits and leaves, leading to a reduction in its concentration within the stems. Importantly, FA enhances the absorption of micronutrients such as manganese (Mn), copper (Cu), and zinc (Zn) through a chelating effect, making these elements more bioavailable to plants [23]. Research by Shi et al. (2023) [36] reported that the application of fulvic acids increased the absorption of nitrogen (N), phosphorus (P), and potassium (K) via tomato fruits by 20.5% to 156%. Our study utilized an organic fertilizer containing both fulvic acids (predominantly) and humic acids at concentrations of no less than 12% and 7%, respectively.

These substances exert a synergistic effect on the plant, enhancing each other's actions. Humic acids (HA) contribute to the improvement of soil structure by activating microbial activity, which in turn increases nutrient availability. Furthermore, HA enhances the water retention capacity of the soil, which is particularly crucial in arid climatic conditions, and stimulates root development, positively affecting the overall biomass of the plants [37]. In addition, humic acids have been shown to influence the microbial community in the soil, promoting the growth of beneficial microorganisms that further contribute to the health of the plants and soil ecosystem.

Fulvic acids, being more mobile and readily absorbed, play a vital role in the transport of nutrients and assist plants in utilizing incoming elements more efficiently. Specifically, fulvic acids improve cellular metabolism, increase the rate of photosynthesis, and promote the synthesis of phytohormones, all of which contribute to the growth and development of plants [38-40].

Bioactive compounds play a vital role in enhancing the nutritional value and health benefits of food products, making them a key focus in the field of functional nutrition [41–46]. Among these compounds, lycopene—a powerful antioxidant found in tomatoes—stands out. Its concentration in fruits depends not only on genetic factors but also on environmental conditions [47]. Studies have shown that the application of fulvic and humic acid-based fertilizers can significantly increase lycopene levels in tomatoes [25, 36]. In the present study, the combined treatment RT-FT (N4) facilitated the most pronounced increase in lycopene levels, ranging from 11.1% to 15.9%, contingent upon the specific hybrid, which may be attributed to enhanced nutrient assimilation by the plants. Among the hybrids investigated, 'Climbo' and 'Syune' demonstrated the greatest increments in lycopene content, at 14.6% and 15.9%, respectively, when compared to the control group. This suggests that the interaction between the plant's genetic traits and the applied organic fertilizers can have a substantial impact on the production of bioactive compounds, enhancing the overall quality of the fruits.

Research conducted by He et al. (2022) [25] indicates that the utilization of fulvic and humic fertilizers markedly improves the quality of lemon fruits, encompassing increases in sugar, ascorbic acid, and dry matter content. Furthermore, findings from Shi et al. (2023) [36] reveal that foliar applications of fulvic acids to tomato plants lead to significant enhancements in vitamin C and sugar concentrations within the fruits, exhibiting increases of 11.4% to 45.9% and 19.2% to 48.5%, respectively.

In our studies, foliar treatment (FT) exhibited a negligible impact on the quality indicators of cluster tomato fruits, with increases in vitamin C content ranging from 9.2 to 11.8 mg/%, total phenolic compounds from 12.6 to 17.7 mg/100g, total sugars from 5.1 to 12.8%, and dry matter from 9.8 to 15.1%. In contrast, the combined treatment RT-FT resulted in the maximum enhancements of vitamin C content, which increased by 13.1 to 15.9 mg/%, phenolic compounds by 14.7 to 22.8 mg/100g, sugars by 13.5 to 21.7%, and dry matter by 14.6 to 22.5% compared to the control group. This highlights the advantage of combining root and foliar treatments to achieve more significant improvements in fruit quality, with the synergistic effects of these two methods fostering more efficient nutrient absorption and utilization.

Vitamin C, sugars, and phenolic compounds are plant metabolites whose concentrations are regulated by both genetic and environmental factors. These metabolites play a crucial role in the nutritional value of plants and their resilience to stressors [25]. The hybrids 'Syune' and 'Climbo' exhibited the highest accumulation of phenolic compounds in their fruits, highlighting their potential for enhancing antioxidant properties. Simultaneously, the hybrids 'Santiana' and 'Adventure' were distinguished by their high levels of ascorbic acid, rendering them particularly valuable for improving nutritional quality. For the accumulation of sugars and dry matter, the best results were observed in the hybrids 'Syune' and 'Prodezo', indicating an improvement in the flavor quality of the tomatoes.

CONCLUSIONS

We have demonstrated the effectiveness of Armenian fertilizers containing fulvic and humic acids in enhancing the quality characteristics of cluster tomato fruits. The combined root and foliar treatment (RT-FT) resulted in the highest accumulation of lycopene, total phenol, ascorbic acid, total sugar, and dry matter when compared to individual root (RT) and foliar (FT) treatments, as well as the control groupThe increased accumulation of bioactive compounds enhances the nutritional profile of these tomatoes, underscoring their potential as functional foods that can contribute to disease prevention and overall health maintenance. Enriched with health-promoting components, these tomatoes can play a significant role in disease prevention and health maintenance, aligning with the growing interest in functional food development.

List of Abbreviations: FA — fulvic acids; HA — humic acids; RT- root treatment; FT- foliar treatment; RT-FT - root treatment- foliar treatment; RZ - Rijk Zwaan; DW- dry weight; FW — fresh weight; g — gram; mg— milligram.

Competing interests: The authors declare that they have no competing interests.

Authors' Contributions: IV and GS designed the study. IV and HM conducted the biochemical analyses, while GS performed the statistical analyses. OS, HM, and LT contributed to the interpretation of the biochemical and statistical results. LKh was responsible for graph preparation. ITs and AV edited the manuscript. All authors reviewed and approved the final version.

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REFERENCES

1. Baek, M.W.; Lee, J.H.; Yeo, C.E.; Tae, S.H.; Chang, S.M.; Choi, H.R.; Park, D.S.; Tilahun, S.; Jeong, C.S. Antioxidant Profile, Amino Acids Composition, and Physicochemical Characteristics of Cherry Tomatoes Are Associated with Their Color. *Antioxidants* 2024, 13, 785. DOI: https://doi.org/10.3390/antiox13070785
2. Felföldi, Z.; Ranga, F.; Roman, I.A.; Sestras, A.F.; Vodnar, D.C.; Prohens, J.; Sestras, R.E. Analysis of Physico-Chemical and Organoleptic Fruit Parameters Relevant for Tomato Quality. *Agronomy* 2022, 12, 1232. DOI: https://doi.org/10.3390/agronomy12051232
3. Bin-Jumah MN, Nadeem MS, Gilani SJ, Mubeen B, Ullah I, Alzarea SI, Ghoneim MM, Alshehri S, Al-Abbasi FA, Kazmi I. Lycopene: A Natural Arsenal in the War against Oxidative Stress and Cardiovascular Diseases. *Antioxidants (Basel).* 2022; 11(2):232. DOI: https://doi.org/10.3390/antiox11020232
4. Long Y, Paengkoum S, Lu S, Niu X, Thongpea S, Taethaisong N, Han Y and Paengkoum P Physicochemical properties, mechanism of action of lycopene and its application in poultry

and ruminant production. *Front. Vet. Sci.* 2024; 11:1364589. DOI: https://doi.org/10.3389/fvets.2024.1364589

5. Khan M, Gul S, Rehman I, Leghari QA, Badar R, Zille-Huma. Protective effect of lycopene against celecoxib induced fat deposition and glycogen reduction in liver cells. *J Taibah Univ Med Sci.* 2024; 19(4): 856-866. DOI: https://doi.org/10.1016/j.jtumed.2024.07.007
6. Przybylska S, Tokarczyk G. Lycopene in the Prevention of Cardiovascular Diseases. *Int J Mol Sci.* 2022; 23(4):1957. DOI: https://doi.org/10.3390/ijms23041957
7. Fernández-Ruiz V, Sánchez-Mata MC, Cámara RM, Domínguez L, Sesso HD. Scientific Evidence of the Beneficial Effects of Tomato Products on Cardiovascular Disease and Platelet Aggregation. *Front Nutr.* 2022; 9:849841. DOI: https://doi.org/10.3389/fnut.2022.849841
8. Mannino F, Pallio G, Altavilla D, Squadrito F, Vermiglio G, Bitto A, Irrera N. Atherosclerosis Plaque Reduction by Lycopene Is Mediated by Increased Energy Expenditure through AMPK and PPARα in ApoE KO Mice Fed with a High Fat Diet. *Biomolecules.* 2022; 12(7): 973. DOI: https://doi.org/ 10.3390/biom12070973
9. Przybylska S, Tokarczyk G. Lycopene in the Prevention of Cardiovascular Diseases. *Int J Mol Sci.* 2022; 23(4): 1957. DOI: https://doi.org/10.3390/ijms23041957
10. Rejali L., Ozumerzifon S., Nayeri H., Williams S., Asgary S. Risk Reduction and Prevention of Cardiovascular Diseases: Biological Mechanisms of Lycopene. *Bioactive Compounds in Health and Disease* 2022; 5 (10): 202-221. DOI: https://www.doi.org/10.31989/bchd.v5i10.975
11. Laranjeira T, Costa A, Faria-Silva C, Ribeiro D, de Oliveira JMPF, Simões S, Ascenso A. Sustainable Valorization of Tomato By-Products to Obtain Bioactive Compounds: Their Potential in Inflammation and Cancer Management. *Molecules* 2022; 27 (5): 1701. DOI: https://doi.org/10.3390/molecules27051701
12. Jiménez Bolaño DC, Insuasty D, Rodríguez Macías JD, Grande-Tovar CD. Potential Use of Tomato Peel, a Rich Source of Lycopene, for Cancer Treatment. *Molecules* 2024; 29 (13): 3079. DOI:https://doi.org/10.3390/molecules29133079
13. Bin-Jumah, M.N., Nadeem, M.S., Gilani, S.J., Mubeen, B., Ullah, I., Alzarea, S.I., Ghoneim, M.M., Alshehri, S., Al-Abbasi, F.A., Kazmi, I. Lycopene: A Natural Arsenal in the War against Oxidative Stress and Cardiovascular Diseases. *Antioxidants* 2022, 11, 232. DOI: https://doi.org/10.3390/antiox11020232
14. Kearney PM, Whelton M, Reynolds K, Muntner P, Whelton PK, He J. Global burden of hypertension: analysis of worldwide data. *Lancet.* 2005; 365 (9455): 217-23. DOI: https://doi.org/10.1016/S0140-6736(05)17741-1
15. Dong S, Zhang J, Ling J, Xie Z, Song L, Wang Y, Zhao L, Zhao T. Comparative analysis of physical traits, mineral compositions, antioxidant contents, and metabolite profiles in five cherry tomato cultivars. *Food Res Int.* 2024; 194: 114897. DOI: https://doi.org/10.1016/j.foodres.2024.114897
16. Collins EJ, Bowyer C, Tsouza A, Chopra M. Tomatoes: An Extensive Review of the Associated Health Impacts of Tomatoes and Factors That Can Affect Their Cultivation. *Biology (Basel)* 2022; 11(2): 239. DOI: https://doi.org/10.3390/biology11020239
17. Rivero, A.G.; Keutgen, A.J.; Pawelzik, E. Antioxidant Properties of Tomato Fruit (Lycopersicon esculentum Mill.) as Affected by Cultivar and Processing Method. *Horticulturae* 2022; 8, 547. DOI: https://doi.org/10.3390/horticulturae8060547
18. Quijia Pillajo, J.; Chapin, L.J.; Martins, E.M.; Jones, M.L. A Biostimulant Containing Humic and Fulvic Acids Promotes Growth and Health of Tomato 'Bush Beefsteak' Plants. *Horticulturae* 2024; 10, 671. DOI: https://doi.org/10.3390/horticulturae10070671
19. Alsudays IM, Alshammary FH, Alabdallah NM, Alatawi A, Alotaibi MM, Alwutayd KM, Alharbi MM, Alghanem SMS, Alzuaibr FM, Gharib HS, Awad-Allah MMA. Applications of humic and fulvic acid under saline soil conditions to improve growth and yield in barley. *BMC Plant Biol* 2024; 24(1): 191. DOI: https://doi.org/10.1186/s12870-024-04863-6
20. Suleimenov, B.; Kaisanova, G.; Suleimenova, M.; Tanirbergenov, S. Influence of Organic Humic Fertilizer "Tumat" on the Productivity of Sugar Beet. *Agronomy* 2024, 14, 1100. DOI: https://doi.org/10.3390/agronomy14061100
21. Martins, E. M., Pillajo, J. Q., & Jones, M. L. (2024). Humic and Fulvic Acids Promote Growth and Flowering in Petunias at Low and Optimal Fertility. *HortScience* 2024; 59 (2), 235-244. DOI: https://doi.org/10.21273/HORTSCI17554-23
22. Zhang, Z.; Ma, Y.; Tian, Y.; Liu, P.; Zhang, M.; Liu, Z.; Zhu, X.; Wang, C.; Zhuang, Y.; Zhang, W.; et al. Co-Application of Coated Phosphate Fertilizer and Humic Acid for Wheat Production and Soil Nutrient Transport. *Agronomy* 2024, 14, 1621. DOI: https://doi.org/10.3390/agronomy14081621
23. Khan, Raza & Khan, Muhammad Zameer & Akhtar, Muhammad & Khan, Abad & Sarwar, S. & Ahmad, Sarir & Hayat, Asim. Growth Stimulation, Metabolic Activities and Fruit Yield of Tomato as Influenced by Fulvic Acid. *Pakistan Journal of Chemistry* 2014; 4. 100-108. DOI: https://doi.org/10.15228/2014.v04.i03.p02
24. Rose, M., Patti, A. F., Little, K., Brown, A., Jackson, W. R., & Cavagnaro, T. A meta-analysis and review of plant-growth

response to humic substances: practical implications for agriculture. *Advances In Agronomy* 2014; 124, 37- 89. DOI: https://doi.org/10.1016/B978-0-12-800138-7.00002-4

25. He, X.; Zhang, H.; Li, J.; Yang, F.; Dai, W.; Xiang, C.; Zhang, M. The Positive Effects of Humic/Fulvic Acid Fertilizers on the Quality of Lemon Fruits. *Agronomy* 2022, 12, 1919. DOI: https://doi.org/10.3390/agronomy12081919
26. Octávio Vioratti Telles de Moura et al., Humic foliar application as sustainable technology for improving the growth, yield, and abiotic stress protection of agricultural crops. *A review, Journal of the Saudi Society of Agricultural Sciences* 2023, 22 (8), 493-513, DOI: https://doi.org/10.1016/j.jssas.2023.05.001
27. Martirosyan H. H., Vardanian I. V., Sargsyan G. Zh. Study and evaluation of racemose tomato hybrids in greenhouses in Armenia*, IOP Conference Series: Earth and Environmental Science* 2023; 1229, 012026. DOI: https://doi.org/ 10.1088/1755-1315/1229/1/012026
28. Rijk Zwaan USA [www.rijkzwaanusa.com] Retrieved December 4, 2024
29. Syngenta Vegetables [www.syngentavegetables.com] Retrieved December 4, 2024
30. Zuorro, A. Enhanced Lycopene Extraction from Tomato Peels by Optimized Mixed-Polarity Solvent Mixtures. *Molecules* 2020; 25, 2038. DOI: https://doi.org/10.3390/molecules25092038
31. Kapur A, Hasković A, Čopra-Janićijević A, Klepo L, Topčagić A, Tahirović I, Sofić E. Spectrophotometric analysis of total ascorbic acid content in various fruits and vegetables, Bulletin of the Chemists and Technologists of Bosnia and Herzegovina. 2012, (38): 39-42
32. Tadevosyan L., Avagyan A., Sargsyan G., Balayan R., Tsereteli I., Harutyunyan Z., Vardanian I., Martirosyan G. Comparative analysis of bioactive components across basil varieties. *Bioactive Compounds in Health and Disease* 2024; 7 (9): 386-397. DOI: https://doi.org/10.31989/bchd.v7i9.1412
33. Pérez M, Dominguez-López I, Lamuela-Raventós RM. The Chemistry Behind the Folin-Ciocalteu Method for the Estimation of (Poly)phenol Content in Food: Total Phenolic Intake in a Mediterranean Dietary Pattern. *J Agric Food Chem*. 2023; 71(46): 17543-17553. DOI: https://doi.org/10.1021/acs.jafc.3c04022
34. Tadevosyan T., Martirosyan G., Tsereteli I., Vardanian I., Zadayan M., Avagyan A. Dynamics of bioactive substances accumulation during cauliflower maturation as a way to ensure crop functional properties. *Functional Foods in Health and Dise*ase 2023; 13(11): 584-594, DOI: https://www.doi.org/10.31989/ffhd.v13i11.1197
35. Wang Rufang, Michiel Lammers, Yury Tikunov, Arnaud G. Bovy, Gerco C. Angenent, Ruud A. de Maagd, The rin, nor and Cnr spontaneous mutations inhibit tomato fruit ripening in additive and epistatic manners, *Plant Science* 2020; 294, 110436, DOI: https://doi.org/10.1016/j.plantsci.2020.110436
36. Shi, X.; Zhang, L.; Li, Z.; Xiao, X.; Zhan, N.; Cui, X. Improvement of Tomato Fruit Quality and Soil Nutrients through Foliar Spraying Fulvic Acid under Stress of Copper and Cadmium. *Agronomy* 2023; 13, 275. DOI: https://doi.org/10.3390/agronomy13010275
37. Canellas, L. P., Olivares, F. L., Aguiar, N. O., Jones, D. L., Nebbioso, A., Mazzei, P., & Piccolo, A. Humic and fulvic acids as biostimulants in horticulture. *Scientia Horticulturae* 2015; 196, 15-27. DOI: https://doi.org/10.1016/j.scienta.2015.09.013
38. Ampong K, Thilakaranthna MS and Gorim LY Understanding the Role of Humic Acids on Crop Performance and Soil Health. *Front. Agron*. 2022; 4: 848621. DOI: https://doi.org/10.3389/fagro.2022.848621
39. Suh, Hye & Yoo, Kil & Suh, Sang Effect of Foliar Application of Fulvic Acid on Plant Growth and Fruit Quality of Tomato (Lycopersicon esculentum L.). *Horticulture, Environment, and Biotechnology* 2015; 55. 455-461. DOI: https://doi.org/10.1007/s13580-014-0004-y.
40. Zhang P, Zhang H, Wu G, Chen X, Gruda N, Li X, Dong J and Duan Z Dose-Dependent Application of Straw-Derived Fulvic Acid on Yield and Quality of Tomato Plants Grown in a Greenhouse. *Front. Plant Sci.* 2021; 12: 736613. DOI: https://doi.org/ 10.3389/fpls.2021.736613
41. Martirosyan G., Avagyan A., Pahlevanyan A., Adjemyan G., Vardanian I., Khachatryan L., Tadevosyan L. Biochemical composition of Armenian chili pepper varieties: insights for functional food applications. *Functional Food Science* 2024; 4(11): 443-451. DOI: https://www.doi.org/10.31989/ffs.v4i11.1495
42. Martirosyan G., Sargsyan G., Sarikyan K., Adjemyan G., Hakobyan A., Avagyan A., Tadevosyan L., Pahlevanyan A. Impact of green manure plants on the yield and bioactive compounds content of lettuce. *Bioactive Compounds in Health and Disease* 2024; 7(9): 457-466. DOI: https://www.doi.org/10.31989/bchd.v7i9.1431
43. Martirosyan G., Sarikyan K., Adjemyan G., Pahlevanyan A., Kirakosyan G., Zadayan M.,Avagyan A. Impact of green technology on content of bioactive components in eggplant. *Bioactive Compounds in Health and Disease* 2023; 6(12): 351-363. DOI: https://www.doi.org/10.31989/bchd.v6i12.1261

44. Martirosyan D.M., Lampert T., Lee M. A comprehensive review on the role of food bioactive compounds in functional food science. *Functional Food Science* 2022; 3(2): 64-79. DOI: https://www.doi.org/10.31989/ffs.v2i3.906
45. Williams, K., Oo, T., Martirosyan, D. M., Exploring the effectiveness of lactobacillus probiotics in weight management: A literature review. *Functional Food Science* 2023; 3(5): 42-54. DOI: https://www.doi.org/10.31989/ffs.v3i5.1115
46. Martirosyan, D.M., Stratton S. Quantum and tempus theories of function food science in practice. *Functional Food Science* 2023; 3(5): 55-62. DOI: https://www.doi.org/10.31989/ffs.v3i5.1122
47. Zharkova I., Pochitskaya I., Efremov D., Plotnikova I., Chusova A., Pronkina A., Harutyunyan N. Assessment of Vitamin -and Mineral- content Stability of Tomato Fruits as a Potential Raw Material for the Production of Functional Food. *Functional Foods in Health and Disease* 2023; 14(1): 14-32. DOI: https://doi.org/10.31989/ffhd.v14i1.1259