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BIOACTIVE COMPONENTS OF TOMATO (*SOLANUM LYCOPERSICUM* L.): COMPARISON OF ORGANIC AND TRADITIONAL CULTIVATION SYSTEMS IN THE MOSCOW REGION, RUSSIA

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SUMMARY

A biochemical analysis sought to determine the bioactive components in two determinate tomato (*Solanum lycopersicum* L.) cultivars, viz., red-fruited cultivar Yamal and orange-fruited cultivar Utenok. For comparative analysis, both cultivars reached growth under two different growing conditions (organic and conventional farming systems) in the same agroclimatic zone. Organically grown tomato cultivars exhibited the highest values of soluble solids (SS), antioxidant activity, and total phenolic compounds. A considerable positive correlation was evident between the antioxidant activity and the total phenolic content. Using gas chromatography-mass spectrometry (GC-MS), 64 different compounds succeeded in their identification in the methanol extract, including 24 organic acids, two phenolic compounds, 15 carbohydrates, five amino acids, 13 sugar alcohols, and five other compounds. Concentrations of 35 identified compounds were higher in organically grown tomatoes. The organically grown tomato cultivar Utenok showed the highest carbohydrate content (52.52%). A considerable positive correlation emerged between the soluble solids and carbohydrates. The results authenticated the significant influence of both cultivars and growing conditions on the fruit's biochemical composition and revealed organically grown tomatoes possess improved nutritional values. The distinct responses of the Utenok and Yamal varieties regarding carbohydrate accumulation confirm that biochemical composition is contingent on both genotypic factors and environmental conditions.

Keywords: Tomato (*S. lycopersicum* L.), cultivars, organic and conventional cultivation, biochemical parameters, DPPH method, primary and secondary metabolites

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Key findings: Organically grown tomatoes (*S. lycopersicum* L.) exhibited the highest concentrations of soluble solids, antioxidants, total carbohydrates, fructose monosaccharides, and secondary metabolites (quininic, glutaric, and caffeic acids) compared to conventional tomatoes.

INTRODUCTION

The tomato (*Solanum lycopersicum* L.) is one of the most important vegetables worldwide. In the present era, the trend toward organic food consumption has substantially grown globally. In the European Union (EU), this sector has considerable support from specific legislation, including different regulations (EC Regulation 889/2008). Notably, prohibiting the use of synthetic chemicals, including pesticides and fertilizers, has prevailed in organic agriculture.

In Russia, tomatoes received classification as a functional foodstuff (GOST R 55577-2013). The standard emphasizes that tomatoes contain biologically active components, found in addition to their basic nutritional values, which reduce the risks of developing various diseases. The rich composition of tomato fruits contributes beneficial properties for better human health. Tomato fruits contain powerful antioxidants, such as carotenoids (primarily lycopene), vitamins C, A, and E, phenolic compounds, and organic acids, as well as various macro- and microelements. Moreover, tomatoes proved low in fats and calories (Kurina *et al*., 2016; Rivero *et al*., 2022; Ouattara and Konate, 2024).

The demand for organically grown plant products is growing steadily. Several past studies recognized organic food has considerable benefits for improving human health, reducing the risks of various diseases, protecting the environment, and preserving biodiversity (Kesse-Guyot *et al.,* 2022; Ropero *et al.,* 2023; Yang *et al.,* 2025). The nutritional and physiochemical properties of tomato fruits differed based on different genotypes and the prevailing growing and environmental conditions (Ali *et al*., 2020; Raza *et al.,* 2022).

Determinate tomatoes (*S. lycopersicum* L.) are the specific plant classification currently under active investigations, primarily owing to their unique growth and fruiting attributes. A key morphological characteristic is their finite apical and determinate growth habit, which imposes specific requirements on their management and cultivation conditions. Such types of determinate cultivars form a compact plant architecture, which inherently minimizes fruit-to-soil contact as compared with indeterminate cultivars. The specific traits of compact size, early maturation, and resistance to environmental stress factors recognized the determinate tomatoes as relevant for cultivation and production in the Russian Federation, particularly in regions experiencing abbreviated summer periods (Kozak and Udayeva, 2015).

The timely study aimed to determine organic farming by comparing it with conventional methods and the impact of growing conditions on the quality and nutritional values of determinate bush tomato cultivars Yamal and Utenok. This research could be a first attempt to conduct this specific comparison. The two-year study also considerably allowed us to determine the tomato cultivars' response to different growing conditions.

MATERIALS AND METHODS

Experimental location

Field studies on tomatoes began in 2022–2023 at experimental sites in the Moscow Region, Russia. Growing organic tomatoes transpired at the experimental site of the Strogoorganic Online Gardening School in Moscow, Russia (55°07'27" N, 37°56'55" E). Conventional tomatoes succeeded in their growth at the experimental site of the Breeding and Seed Production Farm, Moscow Region, Russia (55° 56′ N, 37° 64′ E).

Climate, experimental field soil, and growing conditions

The climate was temperate continental. The experimental soil had a sod-podzolic medium loamy classification in the Moscow Region. Microclimatic impacts were notable during site selection. Based on data from nearby meteorological stations, key climate parameters—including precipitation, hydrothermal conditions, and temperature—showed no statistically significant differences between the two sites during the growing season. Given the identical slope aspect and soil texture, we conclude that the influence of the fertilization system far exceeds any potential effects of spatial microclimatic variability. The average basic agrochemical parameters of the soil during 2022–2023 appear in Table 1. The key difference between the growing conditions was the fertilizer regimen. Conventional cultivation utilized mineral fertilizers containing soluble inorganic nitrogen (N) and other essential minerals (potassium-K, phosphorus-P, calcium-Ca, sodium-Na, magnesium-Mg, iron-Fe, and zinc-Zn), along with commercial chemical pesticides. This approach was consistent with the standard agronomic recommendations for growing tomatoes in the Central regions of the Non-Black Earth Zone of Russia (Kozak, 2012).

In contrast, the organic cultivation system relied exclusively on organic manures and strictly prohibited the use of synthetic fertilizers and pesticides. Pest control management in this system used plant extracts (infusion of the vegetative part of *Chelidonium majus* L. plants and *Urtica dioica* plants). Tomato cultivation occurred from May to September, carrying out the planting scheme of 70 cm × 70 cm, consistent with a full harvest cycle.

Plant material and chemicals

The study utilized fruits from two early and determinate cultivars of tomato (*S. lycopersicum* L.): Utenok (orange-fruited) and Yamal (red-fruited) (Figure 1). Both tomato cultivars comprised the list in the State Register of the Russian Federation. These cultivars were products developed by the breeder V.I. Kozak in Moscow, Russia. Ensuring representative sampling and compensating for potential compositional variability enabled the fruit samples' collection to come from different areas of the field, comprising 3–5 ripe tomatoes from at least 10 bushes. All the reagents, solvents, and standards used were of analytical quality (minimal purity 99%) and bought from Sigma Aldrich, USA, and Merck, Germany.

Plant preparation and extraction

Representative tomato samples weighing 500 g entailed homogenization using an IKA 11 basic analytical homogenizer (Germany). For analysis, extraction of 0.5 g of the crushed tomato fruit fraction proceeded with 20 ml of bi-distilled water (to determine the antioxidant activity of aqueous extracts and the sum of phenolic compounds) and 10 ml of pure methanol (to determine the antioxidant activity of alcohol extracts and study the composition of metabolites) for 24 h. These extracts received centrifugation at 4000 g on a Rotofix 32A (Hettich, Germany) for 20 min, with the supernatant used for different measurements.

Table 1. Agrochemical characteristics of soil.

Observations	pH_{KCl}	Humus (%)	N (mg/kg soil) (by Kornfield)	P_2O_5	K_2O
				mg/100 g air-dry soil (by Kirsanov)	
Average values 2022–2023	5.1	2.4	4.7	18.0	15.1
Optimal values for tomatoes	5.5-7.0	> 1.6%	3.5-4.6	12-13	13-15


Figure 1. General view of *Solanum lycopersicum* plants with fruits.

Biochemical analysis

In biochemical analysis, the soluble dry matter (TSS %) determination was via the refractometric method (GOST ISO 2173, 2013), expressing the values in percentage. The total dry matter content detection was by the thermographic method (GOST.33977, 2016), using analytical scales VIBRA (Shinko Denshi, Co., Ltd., Japan) and drying cabinet SNOL (Lithuania) with forced air convection.

Antioxidant activity by DPPH (AA)

The measurement of samples' radical activity used 2,2-diphenyl-1-picrylhydrazyl (DPPH) following the methodology of Chen *et al*. (2013). The alcoholic (pure methanol) and aqueous extracts (1 ml) sustained mixing with 4 ml of DPPH solution (0.025 g radical in 100 ml methanol). The absorbance of the extract gained determination on a Jenway spectrophotometer (6405 UV/VIS, England) at 517 nm. The lower absorbance of the reaction mixture indicates a higher level of free radical scavenging activity. All the measurements ensued in triplicate. Radical sorption activity calculation as a percentage had the formula below:

$$\text{DPPH radical-scavenging (\%)} = ([AC - AAt] / AC) \times 100$$

Where AC = DPPH solution absorption, and AAt = absorption in the antioxidant presence.

Total polyphenol compounds (TPC)

The total polyphenol compound, as determined, employed the Folin–Ciocalteu reagent method as described by Velioglu *et al*. (1998). The 0.1 ml of each sample extract incurred mixing with 0.1 ml of the Folin-Ciocalteu, 1 ml of 20% (w/v) sodium carbonate, and 8.8 ml of distilled water, with the final mixture shaken and then incubated for 30 min in the dark at room temperature. The absorbance measurement at 750 nm used a Jenway UV-Vis spectrophotometer. Gallic acid (25–250 mg/L; R^2 = 0.996) served as the standard, expressing the results in mg/g gallic acid equivalents and mg of gallic acid (GAE) calculated on the wet weight of tomato fruits.

Gas chromatography-mass spectrometry

A non-targeted analysis using gas chromatography-mass spectrometry (GC-MS) succeeded in assessing the differences between organic and conventional growing conditions. The use of a JMS-Q1050GC chromatograph (JEOL Ltd., Japan) also ran the analysis, comprising a capillary column DB-5HT (Agilent, USA) (length 30 m, inner diameter 0.25 mm, film thickness 0.52 μm, and gas carrier-helium). The temperature gradients during the analysis were within the range of 40 °C–280 °C. The injector and interface temperature was 250 °C, while the ionic source was 2.0 mL/min, split-flow injection mode, with the sample injected in a volume of 2 mcl of the evaporated extract. The analysis lasted for 60 min. The derivation held using silylation reagent N, O-Bis(trimethylsilyl) trifluoroacetamide (BSTFA) followed the method described in past studies. Identification of the substances continued according to NIST-5 National Institute of Standards and Technology (USA) retention behavior and mass spectra. The scanning range was 33–900 m/z, while the identification of substances credibility was within 75%–98%.

Statistical analysis

The compilation of the recorded data proceeded by using Statistica 7 and Excel 7.0 for Windows. All the analyses performed had five replicates. Tabulated data presentation was mean ± standard error and coefficient of variation (V %).

RESULTS AND DISCUSSION

Soluble dry matter

The total soluble solids (TSS) estimation sought to determine the content of total monosaccharide and disaccharide concentration in the plant extracts (Kurina *et al.,* 2021; Mendelová *et al*., 2021). The TSS Brix degrees (°Brix) were the unit used. The determination of soluble dry matter content (expressed in °Brix or % sucrose in cell sap) served as the main measurable indicator for determining tomato ripeness and assessing its suitability for further processing (Higashide, 2022; Kasimatis *et al.,* 2022). The results analysis revealed significant differences among the tested tomato samples for TSS content (Figure 2).

The highest average TSS content resulted in the tomato cultivar Yamal (6.57 °Brix), followed by the orange cultivar Utenok (6.33 °Brix) grown with organic conditions. Tomato cultivars grown conventionally had 0.4% and 0.1% less soluble solids content than organic tomatoes, respectively. Thus, the TSS content in tomatoes depends on cultivars and cultivation methods. The results agreed with several past studies showing that tomatoes grown with organic farming contain more nutrients, including soluble solids and dry matter, than tomatoes grown with conventional agriculture (Turhan and Özmen, 2021; Kurzyna-Szklarek *et al*., 2022). However, the results on the effect of organic and conventional technologies on tomato fruit quality still need further probing, as Vélez-Terreros *et al*. (2021) reported no differences in quality between organically and conventionally grown tomato species.

Dry matter content

Dry matter content is one of the most important indicators of tomato fruit quality. By growing tomatoes under the organic system, in both cultivars, the dry matter content was higher than under the conventional cultivation. By comparing the cultivars, the cultivar Yamal fruits were higher (by 1.2%) than the cultivar Utenok (by 0.4%) (Figure 3). The most active accumulation of dry matter in tomatoes grown under an organic system was evident in fruits of the orange-colored cultivar Utenok, compared with the accumulation in the fruits of the red-colored cultivar Yamal. Compared with conventional tomatoes, the higher dry matter accumulation in organic tomatoes also appeared in past studies (Dabiré *et al*., 2021; Kurzyna-Szklarek *et al*., 2022).

Antioxidant activity and phenolic compounds

Tomato fruits are an important food source of antioxidants (Raza *et al.,* 2022). The ability of tomato extracts to inactivate DPPH+ free radicals served as an indicator of total antioxidant capacity and total phenolic content (TPC) (Table 2). Extracts of both tomato cultivars grown under the organic system had higher antioxidant activity than the extracts obtained from tomatoes grown under the conventional system. Interestingly, the differences between the antioxidant activity of alcoholic and aqueous extracts of tomatoes grown under organic and conventional systems for both cultivars were close as 2.64% and 2.41% in the cultivar Utenok and 2.25% and 1.06% for the cultivar Yamal. Drakou *et al*.

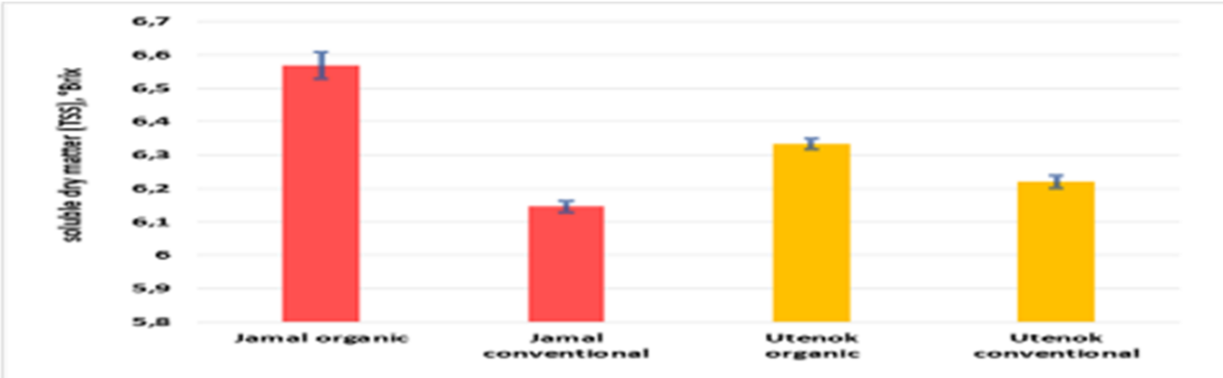

Figure 2. Total soluble solids content in tomatoes (° Brix); bars representing the standard errors of the data (Sx).

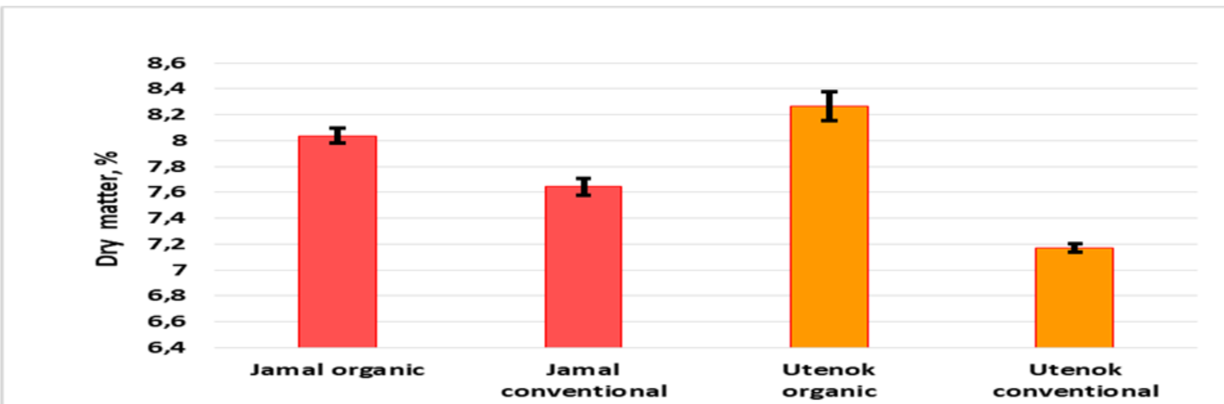

Figure 3. Tomato dry matter content (%); bars represent standard errors of the data (Sx).

Table 2. Antioxidant activity of aqueous (AAA) and methanol (AAM) extracts expressed in percentage and total polyphenol content (TPC) expressed in mg gallic acid equivalent (mg GAE/g TW) in tomatoes (mean ± standard deviation) and coefficient of variation (V %).

Samples	Determined indicators (X ±s)		
	AAA	AAM	TPS
Utenok organic	15.98 ± 0.13	19.16 ± 0.02	0.238 ± 0.02
V%	0.83	0.11	8.73
Utenok conventional	14.13 ± 0.08	16.54 ± 0.07	0.221 ± 0.01
V%	0.58	0.41	4.05
Jamal organic	15.58 ± 0.04	17.81 ± 0.09	0.206 ± 0.05
V%	0.55	0.55	2.66
Jamal conventional	14.52 ± 0.04	15.07 ± 0.05	0.188 ± 0.01
V%	0.25	0.32	4.45

(2015) also reported that tomatoes grown under organic systems showed higher antioxidant activity with aqueous and alcoholic extracts than conventionally grown tomatoes. The levels of some antioxidants tended to be higher in organic products as activated by natural mechanisms of plant defense systems against various pests and diseases and other stressors (Drakou *et al*., 2015). Previous studies enunciated that antioxidant contents in tomatoes depend on the cultivars and growing conditions (Rusu *et al*., 2023).

Both tomato cultivars were notable with increased total phenolic contents when grown organically. The highest value of the sum of phenolic compounds appeared in the cultivar Utenok (0.238 mg GAE/g TW) under the organic cultivation. The low coefficient of variation of the antioxidant activity and total phenolic compounds revealed the relative uniformity in obtained data. The topmost correlation (r = 0.82) was evident between the antioxidant activity of the alcoholic extract and the TPS content in tomatoes.

The coefficients of variation (CV) for the antioxidant activity of aqueous (AAA) and methanol (AAM) extracts and the total polyphenol content (TPC) ranged from 0.2% to 8.72%, revealing the highest degree of uniformity and reliability of the obtained data. Ochoa-Velasco *et al.* (2016) also concluded that higher DPPH activity showed an association with higher content of antioxidants such as phenols. Thus, the study results were greatly analogous to past findings.

Gas chromatography-mass spectrometry

GC-MS analysis showed the content of primary and secondary metabolites in tomato fruits was dependent on cultivation technologies. The detected different compounds totaled 64 in alcohol extracts of tomatoes. These included 24 organic acids, two phenolic compounds (vanillic acid and caffeic acid), 15 carbohydrates, five amino acids, 13 organic alcohols, and five other compounds (Table 3). In organically grown tomato cultivars, the concentrations of 35 identified compounds were higher, of which the most important were the glutaric, quinic, and caffeic acids. In tomato fruits, organic acid is one of the most essential properties from a commercial viewpoint and has a considerable influence on the sensorial qualities of the final product. The acids—caffeic, glucopyranuronic, fumaric, idonic, vanillic, and quininic—and chiro-inositol and sclareol are the most critical components for human health. These bioactive compounds improve metabolism and exhibit antioxidant and therapeutic effects (Magiera *et al.,* 2025). Carbohydrates and organic acids in tomato fruits were the main components that determine taste and aroma and also play a crucial role in the generation of cell turgor (Felföldi *et al*., 2021; Junior *et al.,* 2022; Distefano *et al*., 2022).

The results further identified nine major carbohydrates, seven of which were monosaccharides (fructose, glucose, sorbose, rhamnose, allose, galactose, and tagatose) and two of which were disaccharides (maltose and turanose) (Figures 4 and 5). Among the monosaccharides, the largest share was from the fructose (13%–40%) in the cultivar Utenok, accumulating two times more fructose under organic cultivation as compared with conventional growing. In the tomato cultivar Yamal, the growing conditions did not significantly affect the fructose content. Glucose accumulation in tomatoes of the cultivar Utenok did not depend on growing conditions and amounted to 3.5%. The cultivar Yamal grown under organic technology accumulated glucose four times more than conventional growing conditions (Figure 4). The observed variations in fructose and glucose accumulation among tomato cultivars are genotype-dependent. This aligns with previous research, notably Atherton and Rudich (2012), Beckles (2012), and De-Vos *et al.* (2011). Mendelová *et al*. (2021) and Sun *et al*. (2022) also reported the dominant saccharides were fructose and glucose, and the minor ones were sucrose, as well as arabinose, xylose, and galactose in tomato fruits. The sorbose content in tomatoes did not exceed 6.5%. Both tomato cultivars accumulated 2–3 times more sorbose when grown organically than in the traditional technology.

Table 3. Component composition of tomato methanol extracts.

No.	Organic acids (24)	Carbohydrates and derivatives Carbohydrates (15)	Amino acids (5)	Sugar alcohols (13)	Other connections (5)
1	Acrylic acid	Allose	Alanine	1,5-Anhydroglucitol	Glucosamine
2	Butanedioic acid	Fructose	Cysteine	2-Butene-1,4–diol	Methyl galactoside
3	2-Butenedioic acid	Galactose	Glutamine	Chiro-Inositol	Ribono-1,4-lactone
4	Citric acid	Glucose	Ornithine	Fucitol	Tetramethyl-succinimide
5	Dodecanedioic acid	Glucopħyranose	5-Oxoproline	Galactinol	Xanthine
6	Erythrono-Pentonic acid	Levoglucosan		Glycerol	
7	Fumaric acid	Mannopħyranose		3-Hydroxy-2,3-dihydromaltol	
8	Galactonic acid	Maltose		Mannitol	
9	Glutaric acid	Methyl- alpha -D-glucofuranoside		Meso-Erythritol	
10	Glucopyranuronic acid	Rhamnose		5-Methylhydantion	
11	Hexonic acid	Ribofuranose		Ribitol	
12	Idonic acid	Sorbofuranose		Sclareol	
13	Malic acid	Tagatose		L-Threitol	
14	Malonic acid	Talofuranose			
15	Mannonic acid	Turanose			
16	3-Mercaptobenzoic acid				
17	Aminomalonic acid				
18	Oxalic acid				
19	n-Octanoic acid				
20	Pentenedioic acid				
21	Pipecolic acid				
22	Quininic acid				
23	Ribonic acid				
24	Stearic acid				
No.	**Phenolic compounds (2)**				
1	Vanillic acid				
2	Caffeic acid				

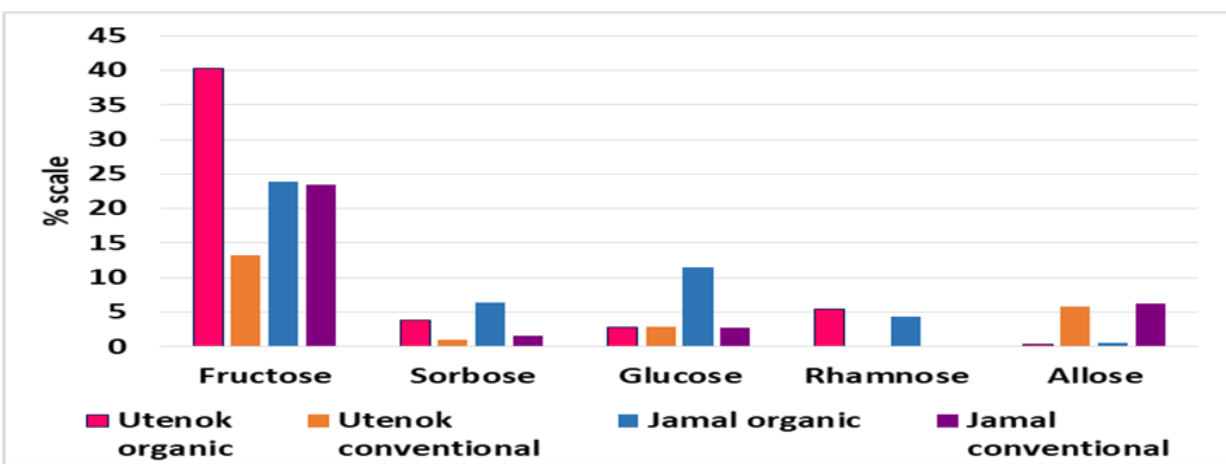

Figure 4. Comparative composition of the main sugars in tomatoes (group 1).

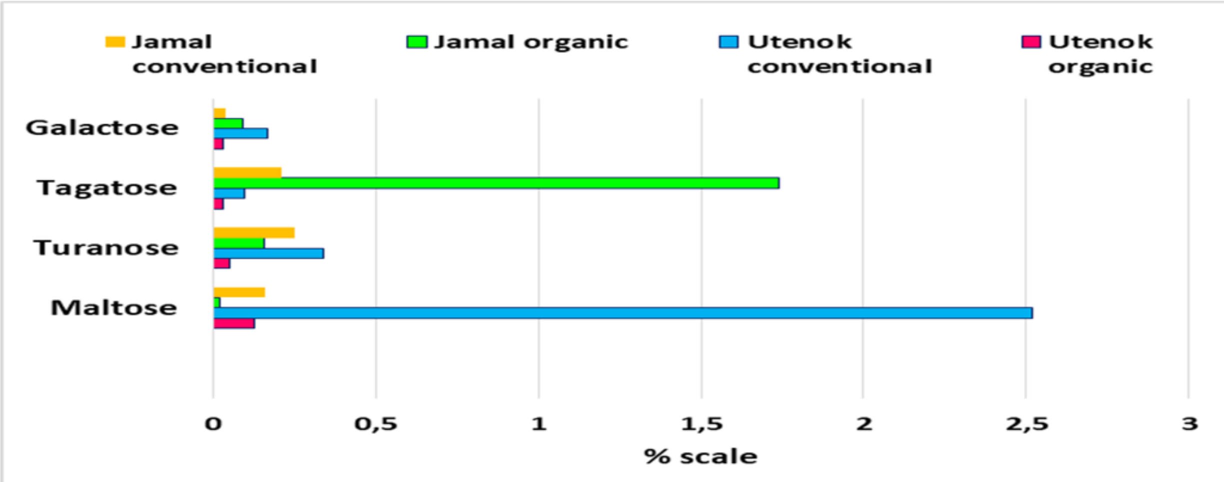

Figure 5. Comparative composition of the main sugars in tomatoes (group 2).

Rhamnose only resulted in organically grown tomato cultivars, and its share was 4.8%–5.0%. Allose accumulation in tomatoes occurred in both cultivars in approximately equal amounts. However, the allose content in tomatoes grown with conventional technology, on average, was five times more (5.1%–5.2%) than in organically grown tomatoes (1%–1.2%) (Figure 4). Maltose and turanose accumulation emerged in both tomato cultivars under the conventional cultivation to a greater extent than under the organic cultivation. In the cultivar Utenok, the maltose content was 16 times more than in the tomato cultivar Yamal. Tagatose accumulates eightfold more and galactose twofold more in the tomato cultivar Yamal under organic growing conditions. The carbohydrate content was 2–3 times higher in the tomato cultivar Yamal under the organic method of cultivation than in the conventional method. In the tomato cultivar color Utenok, on the contrary, the carbohydrate content was 2–3 times higher under the conventional method of cultivation than in the organically grown tomatoes (Figure 5). Mijailovic *et al*. (2021) have also reported that sugars serve as a source of energy as well as act as signaling molecules that influence plant growth and development, physiology, and immunity.

Conversely, in the tomato cultivar Utenok, the carbohydrate content was 2–3 times higher with the conventional cultivation method than the organic method (Figure 5). The monosaccharides, tagatose and allose, and the disaccharides, turanose and rhamnose, discovered in the tomato cultivars Utenok and Yamal were the rare sugars. Discussions on the role of allose as a signaling molecule in crop plants also emerged in past studies (Chahed *et al*., 2022). The role of rhamnose in interaction with tomato pathogens reached authentication in a previous study (Santhanam *et al*., 2017). The difference in turanose and maltose content received a fundamental explanation from the C/N balance theory. Turanose and maltose are important plant metabolites, with maltose involved in energy metabolism, playing a role in stress protection. Meanwhile, turanose acts as a signaling agent, activating genes responsible for plant defense when the plant senses a resource deficiency or other external influences. The predominance of these sugars in traditional tomato cultivation revealed a relation to metabolic intensity and the specific physiological stress experienced by plants. Intensive mineral nutrition in conventional farming stimulates rapid growth and active photosynthesis. In organic systems, slow release of nitrogen occurs, and plant metabolism is more stable, with sugars distributed more evenly. Furthermore, conventional farming involves the use of synthetic crop protection products, which imposes additional stress (De-Vos *et al*., 2011). Metabolomic studies have shown that conventional farming leads to higher concentrations of maltose and turanose than in organically grown tomatoes (Moing *et al*., 2023). Thus, our study confirms the findings of other authors that conventional fertilization (nitrogen, phosphorus, and potassium) activates synthesis pathways for rare disaccharides.

The results enunciated that traditional and organic growing conditions influence the accumulation of carbohydrates and other substances in tomatoes, as well as the cultivar fruits and color. The highest amount of accumulated carbohydrates was evident in the organically grown tomato cultivar Utenok (52.52%), followed by the cultivar Yamal (48.06%). A considerable correlation (r = 0.908) between soluble solids and carbohydrate content also existed. Thus, GC-MS is a key analytical method for identifying bioactive components and confirming differences in primary and secondary metabolite composition between the conventional and organic cultivation methods, even between cultivars. The results were highly consistent with past studies in tomatoes (*S. lycopersicum* L.) (Kurina *et al*., 2021; Raza *et al*., 2022).

CONCLUSIONS

The study revealed the organically grown tomato cultivars Yamal and Utenok accumulate higher levels of soluble solids, sugars, and antioxidant compounds. Moreover, their synthesis of primary and secondary metabolites was more active than in conventionally grown tomatoes. The results confirmed the influence of cultivars and fruit color on the biochemical composition of tomatoes. The cultivar Utenok exhibited the best performance in studied traits, which can be beneficial in breeding programs aimed at enhancing desirable tomato biochemical traits. Additionally, organically grown tomatoes can serve as a natural source of antioxidants to better support human health. Bioactive components identified through GC-MS enabled the differentiation of conventional and organic tomato cultivation methods.

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