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Phytochemical profile analysis of tomato cultivars based on color and size

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ABSTRACT

This study aimed to comprehensively evaluate the phytochemical profiles of eight tomato cultivars differing in fruit color and size. The analysis encompassed the determination of mineral composition, hormone levels, organic acids, amino acids, sugars, lycopene, vitamin C, total phenolic content, total flavonoid content, and antioxidant activity. The findings demonstrated that fruit color and size significantly influence the nutritional and phytochemical quality of tomato fruits. Red-colored and small-fruited cultivars, particularly Idolini and Confetto, exhibited higher levels of lycopene, vitamin C, flavonoids, phenolic compounds, and antioxidant activity. In contrast, yellow and orange-colored cultivars such as Maggino and Operino displayed lower acidity and higher sweetness. The large-fruited cultivar Siranzo showed lower levels of minerals and phytochemicals but offered a milder and sweeter flavor profile. Red cultivars generally had richer organic acid profiles, while yellow and orange types exhibited lower concentrations. The results suggest that small, red-colored tomatoes may be ideal for health-conscious consumers due to their high antioxidants and nutrient content. Meanwhile, yellow and orange cultivars suit consumers who prefer milder flavor profiles. These findings provide valuable insights for quality-oriented breeding strategies and informed cultivar selection in tomato production and marketing.

1. Introduction

Tomato (*Solanum lycopersicum* L.) belongs to the Solanaceae family and is cultivated worldwide for fresh consumption and processing (Butelli et al., 2008; Knapp and Peralta, 2016). The tomato fruit is rich in phytochemicals including phenolic compounds, flavonoids, vitamin C, minerals, amino acids and lycopene, which have strong antioxidant properties (Abdullahi et al., 2016; Elbadrawy and Sello, 2016; Navarro-González et al., 2011; Ramos-Bueno et al., 2017). Additionally, sugar components such as glucose, fructose, sucrose, and organic acids are key factors influencing fruit flavor and quality. These components not only enhance the nutritional value of tomatoes but also offer protective health benefits (Ali et al., 2020; Tang et al., 2021). Regular consumption of tomatoes has been shown to contribute to the prevention of cancer, diabetes, cardiovascular diseases, eye disorders, and constipation. Additionally, it has been linked to the reduction of blood pressure, improvement in blood circulation, enhancement of body fluid balance, reduction in cholesterol levels, detoxification of toxins, alleviation of inflammation, prevention of premature aging, and the enhancement of digestive function (Campestrini et al., 2019; Navarro-González et al., 2011; Salehi et al., 2019; Vats et al., 2022; Zhu et al., 2020).

In the domestication and breeding of tomatoes, breeders have primarily focused on yield, disease resistance, fruit size, and visual appeal as key objectives of modern cultivars (Aydın, 2024a; Aydın, 2024b; Aydın et al., 2024; Gascuel et al., 2017; Klee and Tieman, 2013). Therefore, the flavor and nutritional content of tomato fruits have often been overlooked indirectly. However, with the rise in living standards worldwide, consumers increasingly prefer tastier and higher-quality fruits and are willing to pay a reasonable premium for this quality. This shift has led to a transformation from yield-oriented breeding to flavor-oriented breeding, with high-yielding, flavorful tomatoes

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becoming the ultimate goal of breeders (Colantonio et al., 2022; Klee and Tieman, 2018). This growing consumer interest has paralleled the scientific rediscovery of tomato flavor. In this context, the genetic basis of tomato flavor components has emerged as a significant area of focus for researchers in recent years (Fernie and Alseekh, 2022). Organoleptic quality is a complex fruit quality trait encompassing aspects such as taste, texture, and aroma (Oms-Oliu et al., 2011). Flavor is perceived through the interaction of odor, taste, and mouthfeel, and is largely determined by the balance between sugars, organic acids, volatile compounds, and free amino acids. Alterations in any of these components can lead to changes in the overall nutritional quality (Campestrini et al., 2019; Gascuel et al., 2017; Vu et al., 2020).

The carotenoid content in tomatoes is highly dependent on the days post anthesis, as the ripening process significantly influences the accumulation of key compounds. As the fruit progresses through different maturation stages, the levels of carotenoids such as lycopene, β-carotene, and lutein undergo substantial changes. During the early stages, chlorophyll dominates, while as ripening advances, chlorophyll degradation leads to a sharp increase in carotenoid synthesis, ultimately determining the fruit's characteristic coloration and nutritional properties (Ilahy et al., 2019; Lenucci et al., 2009).

Although earlier studies on the phytochemical composition of tomatoes often focused on a single cultivar or individual compounds, recent research has increasingly emphasized the comparative analysis of multiple tomato genotypes differing in fruit type, size, and color under varying cultivation systems. For instance, Chea et al. (2021) investigated morphological, leaf nutrient, and fruit quality traits across diverse tomato cultivars under organic low-input conditions. Similarly, Erika et al. (2020) examined how tomato biodiversity reflects on nutrient density and yield performance in organic open-field systems. These studies highlight the importance of integrating phenotypic diversity into phytochemical evaluations to better understand cultivar-specific nutritional potential and environmental adaptability. In particular, it is stated that lycopene, β-carotene and flavonoid content show variation in cultivars with different fruit colors such as red, yellow and orange; and that the sugar/acid ratio determines the taste profile in large and small-sized fruits (Kurina et al., 2021). In addition, the concentration of phenolic compounds is directly related to both genetic differences within the cultivar and growing conditions (Kaboré et al., 2022; Londoño-Giraldo et al., 2020; Periago et al., 2002). In this context, comparing the phytochemical profiles of tomato cultivars based on fruit color and size can provide valuable insights for improving flavor, aroma, and health-beneficial compounds. In our study, eight different tomato cultivars with different colors and sizes were evaluated comprehensively.

2. Material and method

The experiment was conducted between March and September 2022 at Krşehir Ahi Evran University (38°08'02"N, 34°07'08"E) in a fully automated and climate-controlled venlo type glass greenhouse. The seeds for the tomato cultivars used in the study were supplied by RIJK ZWAAN (Rijk Zwaan Zaadteelt en Zaadhandel B.V.). Table 1 provides information on tomato cultivars.

Table 1
Characteristics of tomato cultivars.

Cultivar Name	Crop Type	Fruit Colour	Fruit Shape	Plant Type
Idolini	Plum	Red	Small San Marzano	Indeterminate
Farbini	Plum	Orange	Small San Marzano	Indeterminate
Solarino	Plum	Red	Elliptical	Indeterminate
Confetto	Plum	Red	Elliptical	Indeterminate
Maggino	Plum	Yellow	Elliptical	Indeterminate
Reddery	Cherry	Red	Round	Indeterminate
Operino	Plum	Yellow-Orange	Pear	Indeterminate
Siranzo	Intermediate	Red	Round	Indeterminate

2.1. Sowing seeds and planting seedlings

Seed sowing was raised in 3 April, with transplanting done in 28 April. Seed sowing was carried out in a 128-cell seedling plug tray filled with a peat:perlite mixture at a 3:1 ratio. Transplantation occurred 25 days after seeding when the seedlings had developed 3–4 true leaves. Proper spacing was maintained, with 25 cm between plants and 100 cm between rows. The cocopeat slabs were saturated for a minimum of 24 h before transplanting. Plants were grown in the greenhouse by irrigation and fertilization until the first true leaf stage. When the seedlings reached planting size, they were planted in cocopeat medium with a distance of 25 cm between rows and 100 cm between rows. Seedlings, three replications with 24 plants each, were planted randomly. Irrigation, fertigation and acclimatization processes (the amount of water and fertilizer was adjusted depending on the plant growth stage and greenhouse temperature) were carried out with an automation system.

2.2. Stock solution and automation system for hydroponic tomato cultivation

The preparation of the irrigation solution and the irrigation duration were carried out using the MASTIA HİDRO automation system from Nutricontrol (Cartagena, Spain). Stock tanks were prepared for the irrigation solution (Table 2), and the electrical conductivity (EC) of the solution was adjusted. While preparing the irrigation solution, stock solutions were adjusted to be A (50 %) and B (50 %). The EC value was set to 2.2 mS/cm until the plants reached the flowering stage, and then adjusted to 2.6 mS/cm during the fruit development phase. The pH value was maintained within the range of 5.5–6.5. The irrigation duration and frequency were optimized to ensure 20 % (v/v) solution drainage from the coconut coir growing medium.

2.3. Plant care procedures and climate conditions in greenhouse

Climate data for the greenhouse growing season are provided in Table 3. The greenhouse cooling (fan-fad cooling) and humidification (high pressure fogging) processes were carried out with an automation

Table 2
Stock tanks and fertilizers.

Tank	Fertilizer	Rate (kg/1000 L)	Provided Nutrients
A	Calcium Nitrate ($Ca(NO_3)_2$)	110	Calcium (Ca), Nitrate (NO_3^-)
A	Iron Chelate (Fe-EDDHA)	5	Iron (Fe)
B	Potassium Nitrate (KNO_3)	30	Potassium (K), Nitrate (NO_3^-)
B	Mono Potassium Phosphate (KH_2PO_4)	25	Phosphorus (P), Potassium (K)
B	Magnesium Sulfate ($MgSO_4$)	40	Magnesium (Mg), Sulfate (SO_4^{2-})
B	Magnesium Nitrate ($Mg(NO_3)_2$)	10	Magnesium (Mg), Nitrate (NO_3^-)
B	Potassium Nitrate (KNO_3)	30	Potassium (K), Nitrate (NO_3^-)
B	Potassium Sulfate (K_2SO_4)	25	Potassium (K), Sulfate (SO_4^{2-})
B	Boric Acid (H_3BO_3)	0.4	Boron (B)
B	Zinc Sulfate ($ZnSO_4$)	0.3	Zinc (Zn)
B	Manganese Sulfate ($MnSO_4$)	0.4	Manganese (Mn)
B	Copper Sulfate ($CuSO_4$)	0.025	Copper (Cu)
B	Sodium Molybdate (Na_2MoO_4)	0.018	Molybdenum (Mo)
C	Nitric Acid (HNO_3)	%50 (HNO_3) % Water	pH adjustment (Acid)

Table 3
Climate data for the greenhouse growing season.

Months	Temperature (°C)		Humidity (%)	
	Day	Night	Day	Night
March	24	15	55	60
April	26	18	53	61
May	26	19	54	61
June	27	19	60	65
July	27	19	61	65
August	27	20	62	65
September	27	20	62	65

system. When the greenhouse temperature exceeded 27 °C, the cooling process was carried out and when the humidity dropped below 50 %, the fogging process was carried out until the humidity increased to 65 %. Following the planting process, the main stem of each plant was secured with a loosely tied nylon rope, while the other end of the rope was attached to a horizontal support wire approximately 3 m above the greenhouse floor. As the plants grew linearly in height, the stems were fastened to the support rope using plastic clips. To promote single-stem growth, pruning operations were conducted weekly, during which side shoots measuring 2–2.5 cm were manually removed. In the first leaf pruning operation, old leaves located at the bottom of the plants, at a height of approximately 0.30–0.45 m, were removed. Side branches and shoots were completely eliminated, preserving only the main stem, allowing the plants to develop a single-stem structure. The main growth point was removed in plants that had grown up to the eighth cluster. Bumblebees were used for pollination, and necessary pesticide applications were performed when diseases or pests were observed. Fruit samples for analysis were collected from the 4th cluster. The fruits were taken from 2 randomly selected plants per replication, with a total of 6 fruits analyzed for each cultivar.

2.4. Determination of minerals

Samples collected from different tomato cultivars were dried in a forced-air oven at 68 °C for 48 h to ensure consistent moisture removal. After drying, the samples were finely ground using a laboratory mill to obtain a homogenous powder suitable for chemical analyses. The total nitrogen content of the fruit samples was determined using the Kjeldahl method, following the standard protocols recommended by the AOAC (2005). The distillation process was performed using a Vapodest Rapid Kjeldahl Distillation Unit (Gerhardt, Königswinter, Germany), ensuring accurate and reproducible nitrogen measurements. For the determination of macro-elements (potassium [K], magnesium [Mg], phosphorus [P], sodium [Na], sulfur [S], and calcium [Ca]) and micro-elements (iron [Fe], zinc [Zn], copper [Cu], manganese [Mn], and boron [B]), an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) was used. The analysis was carried out in accordance with the AOAC guidelines (2005). Calibration curves for all measured elements were established and are presented in Supplementary File 1.

2.5. Determination of Hormones

Extraction and purification procedures were performed according to the protocol of Kuraishi et al. (1991). 80 % methanol at –40°C was added to one gram of fresh fruit sample. After homogenizing for 10 min using an Ultra-Turrax (IKA, T-25) homogenizer, the solution was incubated for 24 h in a dark environment and the samples were dried with evaporator pumps at 35°C. Dried samples were solubilized using 0.1 M KHPO (pH 8.0) and a Sep-Pak C-18 (Waters) cartridge was used for further specific separation. The hormones absorbed by the cartridge were transferred to the tubes using 80 % methanol. Hormones were analyzed by HPLC using a Zorbax Eclipse-AAA C-18 column (Agilent 1200 HPLC) and the mobile phase was adjusted to pH 4.98 with 13 % acetonitrile, the flow rate was 1.2 ml min^{-1} and the column temperature was 25°C. A UV detector at 265 nm was used for the detection of gibberellic acid (GA), salicylic acid (SA), indole acetic acid (IAA), abscisic acid (ABA), jasmonic acid (JA), zeatin and cytokinin (Turan et al., 2014). Calibration curves for all measured hormones were established and are presented in Supplementary File 1.

2.6. Determination of organic acids

Organic acids were determined using ultrafast liquid chromatography (UFLC) equipped with DAD (Shimadzu, Kyoto, Japan), according to the method outlined by Barros et al., (2013). Each determined organic acid compound was identified and quantified by comparing the calibration curves specified in its commercial standards with the area of the peaks recorded at wavelengths between 215 nm and 245 nm, based on the absorption maxima of the respective organic acids. The standards of organic acids (oxalic, propionic, tartaric, butyric, malonic, malic, lactic, citric, maleic, fumaric, succinic acids) were purchased from Sigma-Aldrich Chemicals Inc., Shangai, China). Plant samples (0.5 g) were homogenized using a pestle and mortar with 2.5 ml of deionized water. The calibration curves of the organic acids are presented in Supplementary File 1. The homogenate was centrifuged at 10,000 rpm for 10 min at 4 °C. The resulting supernatant was stored at −18 °C for further analysis. One milliliter of the centrifuged liquid of the stock solution was filtered through a 0.45 μm Millipore size membrane filter and then injected in UFLC. The identification and quantification of acids were performed by injecting 20 μL stock solution to separate different acids on a Supelcogel TMC-610H column (30 cm × 7.8 mm, i.e., Supelco, Bellefonte, PA, USA) by using 0.01 M sulphuric acid as a mobile phase at a flow rate of 0.8 ml/min. The results were expressed in ng μL−1 of wild edible plant extract.

2.7. Determination of amino acids

To determine amino acid analysis, 0.1 N HCl added 1 g sample, homogenized with ultraturraks, and incubated in 4°C at 12 h. After samples were centrifuged at 1200 rpm for 50 min, supernatants were filtered through 0.22 m (Millex Millipore). Then supernatants were transferred tovial and vials for amino acid acid analysis in HPLC as described by Antoine et al., (1999) and Aristoy & Toldrá, (1991). Aspartate, glutamate, asparagine, serine, glutamine, histidine, glycine, theonine, arginine, alanine, tyrocine, cystine, valin, methionine, tryptophan, phenylalanine, isoluecine, leucine, lysine, hydroxyproline, sarcosine, proline quantity of lichen samples determined as pmol/μL after 26 min derivation process in HPLC. The calibration curves of the amino acids are presented in Supplementary File 1.

2.8. Determination of vitamin C, total phenolics, total flavonoid, total antioxidant and lycopene

Homogenates were assayed for vitamin C, total phenolic content and antioxidant activity. Ascorbic acid (vitamin C) of samples was quantified with the reflectometer set of Merck Co (Merck RQflex). For extraction, fruit homogenates obtained with a blender were extracted with a buffer containing acetone, water and acetic acid (70:29.5:0.5, v/v/v) for 1 h in darkness (Singleton and Rossi, 1965). This extract was filtered and used for phytochemical analysis. Total phenolics were determined colorimetrically using FolinCiocalteu reagent as described by Slinkard and Singleton (Slinkard and Singleton, 1977). Gallic acid was used as the standard and results were expressed as mg gallic acid equivalents per g fresh weight basis. Total antioxidant capacity of samples was determined by β-carotene bleaching assay. In the β-carotene bleaching assay, antioxidant capacity is determined by measuring the inhibition of the volatile organic compounds and the conjugated diene hydroperoxides arising from linoleic acid oxidation (Kaur and Kapoor, 2002). Antioxidant capacities of the samples were compared with those of the synthetic

antioxidant butylated hydroxyanisole (BHA) and the blank. Fresh sample (1 gram) was homogenized with ultraturraks, incubated at 4°C for 12 h, and centrifuged at 1200 rpm for 50 min whereas supernatants were filtered through 0.22 m. Measurement of the flavonoid concentration of the tomato skin, pulp and seed were based on the method described by Park et al., (1997), with a slight modification. A 1 ml aliquot of the sample was added to a test tube containing 0.1 ml of 10 % aluminum nitrate, 0.1 ml of 1 M potassium acetate and 3.8 ml of methanol. The mixture was then incubated for 40 min at room temperature and the absorbance was determined at 415 nm. Spectrophotometric analysis was performed using a five-point calibration curve generated with pure quercetin (Sigma) as the standard. The content in the tomato fruits samples were expressed in micrograms of quercetin equivalents (QUE) per ml of a sample (Özdemir et al., 2016). Lycopene content of tomatoes was determined by spectrophotometric method. For this purpose, approximately 0.5 g of sample was weighed into a 50 ml falcon tube and 5 ml of 0.05 % BHT containing acetone, 5 ml of 95 % ethanol and 10 ml hexane were added. Then, it was subjected to extraction for 15 min at 180 rpm and 4°C in an orbital shaker. At the end of this period, 3 ml of ultrapure water was added to the mixture and shaking was continued for another 5 min. After extraction, the falcon tubes were kept at room temperature until phase separation occurred and measurements were made from the upper phase containing lycopene. Measurements were carried out on a UV-Vis spectrophotometer (UV-1800, Shimadzu, Japan) at 503 nm and the lycopene contents of the samples were calculated with the help of the equation [Lycopene amount (mg kg^{-1} fresh sample)= (A503x31.2) sample $amount^{-1}$ (g)] (Fish et al., 2002). The calibration curves of the vitamin c, total phenolics, total flavonoid, total antioxidant and lycopene are presented in Supplementary File 1

2.9. Determination of sugars

Carbohydrate standards—including fructose, glucose, sucrose, and total sugar—were purchased from Sigma-Aldrich (Shanghai, China). For sugar extraction, 2 g of dried tomato fruit powder was mixed with 20 ml of 80 % (v/v) ethanol. The mixture was subjected to ultrasonication for 2.5 h to enhance extraction efficiency. Sugar analysis was performed using a high-performance liquid chromatography (HPLC) system (Agilent Technologies, 1100 series, USA) equipped with an isocratic pump, autosampler, and a refractive index detector (RID, 1260 series). The method followed was based on Harada et al. (2004), with modifications where necessary to optimize performance. Isocratic elution was achieved using a water/acetonitrile solvent system (30:70, v/v) on a Purospher® Star NH_2 column (250 × 4.6 mm, 5 µm; Merck Millipore, Darmstadt, Germany). The flow rate was set at 1.0 ml/min, with an injection volume of 10 µL. Both the RID and column oven temperatures were maintained at 40 °C throughout the analysis. Sugar quantification was carried out using the internal standard method, with erythritol added as the internal standard to both calibration solutions and sample extracts. Results were calculated based on calibration curves and expressed as grams per 100 grams of dry weight (g/100 g dw). Calibration curves and representative chromatograms are presented in Supplementary File 1.

2.10. Determination of hue angle value and average fruit weight

Analysis of the CIE L, a*, b*, chroma (C) and hue angle value (ho) components of the samples was performed using the Minolta CR 400 device (Konica Minolta, Japan). Measurement in tomato samples was performed by taking the average of the color values read from three different points using the Minolta CR 400 device. Before the measurements, the device was calibrated with the calibration plate (Özdemir, 2001). Hue angle is calculated with the formula = (180/3.141592654) *ATAN (b*/a*). The hue value, or the angle of the color, changes according to where the color is in red, green, and blue (Hue angle 0°: Red 60°: Yellow 120°: Green 180°: Cyan 240°: Blue 300°: Magenta 360° or 0°: Red again). The average fruit weight was measured using a scale with a sensitivity of 0.01 gs.

2.11. Statistical analysis

To determine the significant differences in phytochemical contents among different tomato cultivars, analysis of variance (ANOVA) was performed. Following the ANOVA results, Tukey's multiple comparison test was used to further detail the differences between groups. These analyses were conducted using Minitab Statistical Software 22 (Minitab, LLC, United States of America (USA). To evaluate the relationships and examine potential linear correlations between parameters such as fruit weight, fruit hue angle, and phytochemical parameters, a correlation analysis was performed. This analysis was conducted using SPSS Statistics software (IBM Corporation, United States of America (USA) and Pearson correlation coefficients were calculated. Finally, to visualize the obtained results and present the phytochemical contents of different tomato cultivars in a comparable format, heat map graphics were created. These visualizations were prepared using Microsoft Excel (Microsoft Corporation,United States of America (USA).

3. Results

3.1. Fruit weight and fruit Colour

Fruit weight and fruit colour (Hue°) values of tomato cultivars are shown in Figs. 1 and 2. Statistically significant differences were determined between the cultivars in terms of fruit weight and fruit colour ($p < 0.01$) (Table 4). The highest fruit weight was obtained in Siranzo cultivar with intermediate product type. The lowest fruit weight was obtained in Solarino and Operino cultivars with plum crop type. The highest Hue° value was recorded in Maggino cultivar with yellow colour, followed by Operino cultivar with yellow-orange colour and Farbini cultivar with orange fruit colour. The lowest Hue° values were recorded in red coloured cultivars (Idolini, Solarino, Confetto, Reddery and Siranzo).

The average fruit weight of the cultivars changed between 9.05 and 140.26 g, while fruit colour (Hue°) values varied between 10.32 and 55.65°. The average fruit weight across the eight cultivars was determined to be 29.09 g, while the average fruit color, expressed as Hue° value, was determined as 23.19°. In terms of fruit weight, the standard deviation of Siranzo (5.67) was slightly higher than the other cultivars, but since this cultivar is generally in the large fruit category, it can be said that the variation can be considered normal. When the standard deviation of the Hue° value of the cultivars was examined, cultivars such as Farbini (4.41) and Operino (3.35) showed a wider variation, indicating that the colour shades may be more variable in the same cultivar (Table 4).

3.2. Macro and micro element

Nitrogen (N), potassium (K) and calcium (Ca) (%) contents in fruit tissues of tomato cultivars are shown in Fig. 3. Statistically, the highest nitrogen was observed in Idolini, Solarino and Farbini cultivars, and the lowest nitrogen was observed in Siranzo cultivar. Potassium values show a more balanced distribution among the cultivars. Idolini, Farbini and Solarino cultivars have high potassium content and are in statistically similar group. Operino Reddery and Siranzo cultivars have lower potassium content. Calcium was lower in all cultivars compared to nitrogen and potassium elements. Calcium was higher in Idolini, Solarino, Confetto and Farbini cultivars with Plum crop type, while Siranzo cultivar had the lowest calcium content.

Fig. 4 shows the phosphorus (P), magnesium (Mg) and sulphur (S) (%) in fruit tissues of different tomato cultivars. The highest phosphorus was determined in Idolini cultivar, and the lowest phosphorus was determined in Siranzo cultivar. Magnesium contents of the cultivars

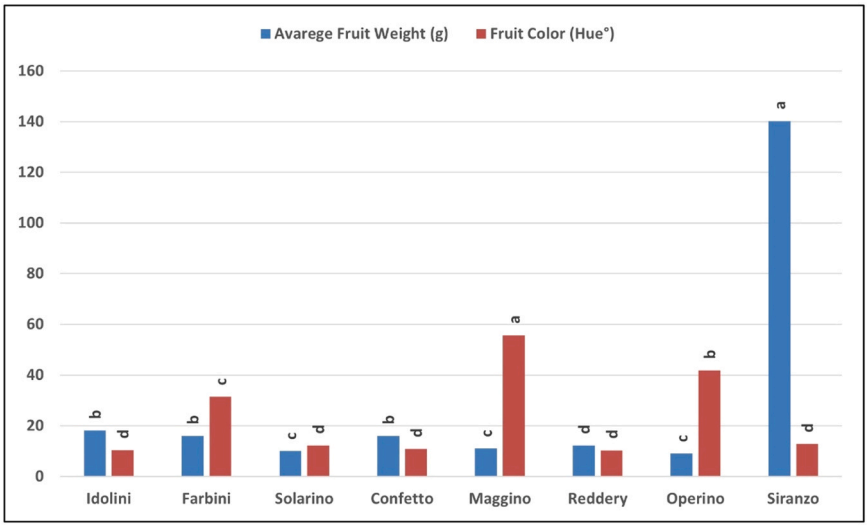

Fig. 1. Average fruit weight and colour (Hue°) of tomato cultivars.

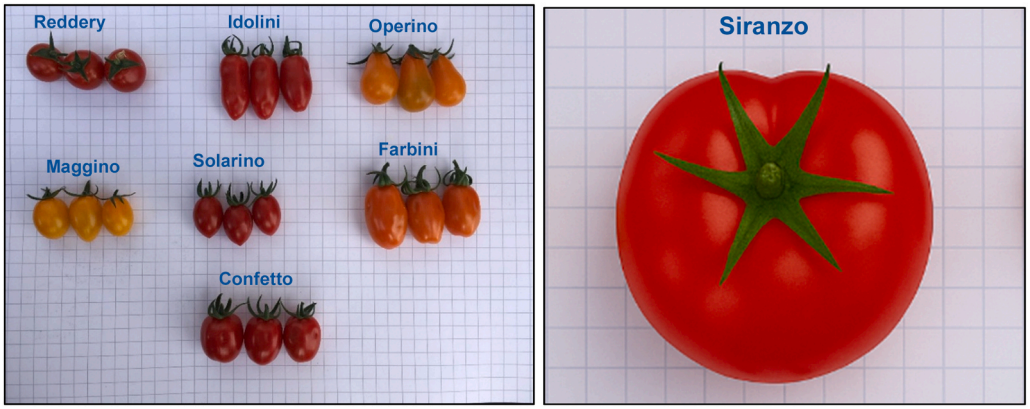

Fig. 2. Tomato cultivars with different fruit colors and sizes.

Table 4
Fruit weight and color (Hue°) values, along with standard deviations, for tomato cultivars.

Cultivar	Avarege Fruit Weight (g)		Fruit Color (Hue°)	
	Mean	StDev	Mean	StDev
Idolini	18.09	1.25	10.36	2.22
Farbini	16.01	1.033	31.45	4.41
Solarino	10.03	1.60	12.26	1.25
Confetto	16.02	2.30	10.87	2.31
Maggino	11.06	2.852	55.65	2.33
Reddery	12.20	2.27	10.32	1.35
Operino	9.05	0.56	41.78	3.35
Siranzo	140.26	5.67	12.80	1.25
Min	9.05		10.32	
Max	140.26		55.65	
Mean	29.09		23.19	
p value	0.001		0.001	

show a similar distribution to phosphorus values. Idolini and Farbini cultivars have the highest magnesium percentage and statistically significant. Siranzo cultivar again has the lowest magnesium content. Sulphur percentages have generally lower values compared to other elements (phosphorus and magnesium). Idolini, Solarino and Farbini cultivars have the highest sulphur percentages, while Maggino, Reddery, Operino and especially Siranzo cultivars have lower sulphur percentages.

In Fig. 5, the micro element contents (Mn, Fe, Zn, Cu, Na, and B) of different tomato cultivars are given in mg kg^{-1} . The highest manganese content was observed in Idolini, Farbini, Solarino cultivars. Operino and Siranzo cultivars have lower values in terms of manganese content. In terms of iron content, Idolini Farbini, Solarino and Confetto cultivars had the highest values, while the lowest value was determined in Siranzo cultivar. Idolini cultivar has the highest zinc content, while Operino cultivar has the lowest value compared to other cultivars. The highest Cu content was determined in Farbini cultivar, while the lowest was determined in Siranzo cultivar. Sodium content was highest in Idolini, Farbini and Operino cultivars, while the lowest was detected in Siranzo cultivar. Boron content was highest in Reddery cultivar and lowest in Maggino cultivar with yellow fruit colour.

The macro and micronutrient contents in the fruit tissues of 8 different tomato cultivars are shown in Table 5 with minimum, maximum values and standard deviations. In terms of macro elements, nitrogen content of the cultivars varied between 1.60 ± 0.01 % (Siranzo) and 3.67 ± 0.16 % (Idolini), while phosphorus content was observed between 0.16 ± 0.01 % (Siranzo) and 0.58 ± 0.06 % (Idolini). Potassium content varied between 1.26 ± 0.03 % (Siranzo) and 2.87 ± 0.06 % (Idolini), while calcium content varied between 0.76 ± 0.06 % (Siranzo) and 1.60 ± 0.06 % (Confetto). Magnesium content varied between 0.15 ± 0.01 % (Siranzo) and 0.58 ± 0.07 % (Idolini), while sulphur content ranged between 0.11 ± 0.01 % (Siranzo) and 0.26 ± 0.02 % (Idolini). In terms of micro elements, manganese content was measured between 16.81 ± 0.61 mg kg^{-1} (Siranzo) and 39.89

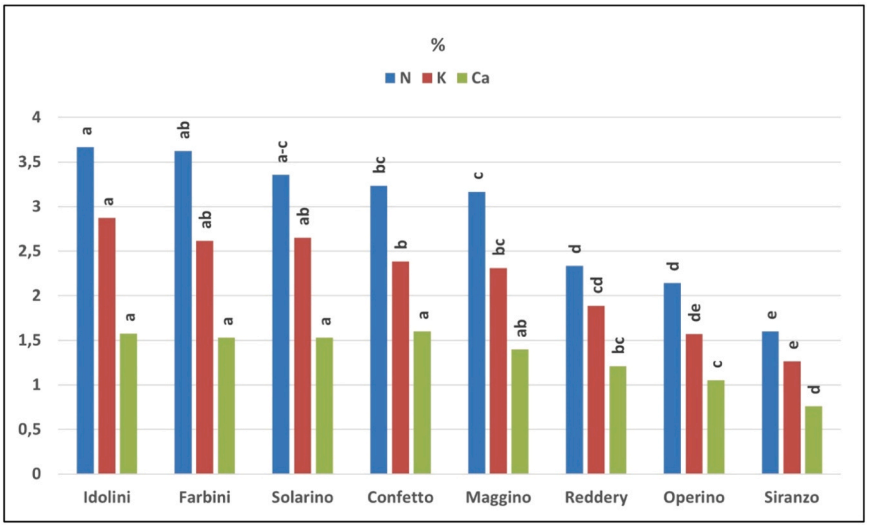

Fig. 3. Macro element nitrogen (N), potassium (K) and calcium (Ca) contents in fruit tissues of tomato cultivars.

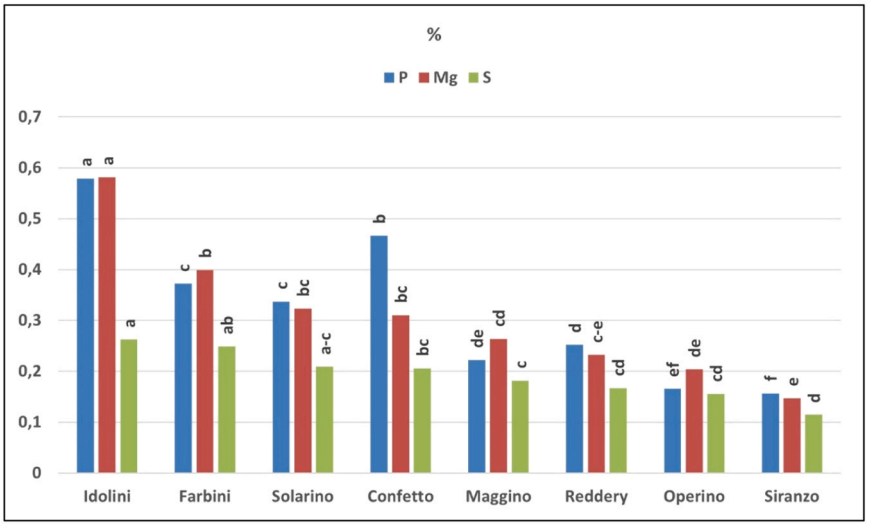

Fig. 4. Macro element phosphorus (P), magnesium (Mg) and sulfur (S) contents in fruit tissues of tomato cultivars.

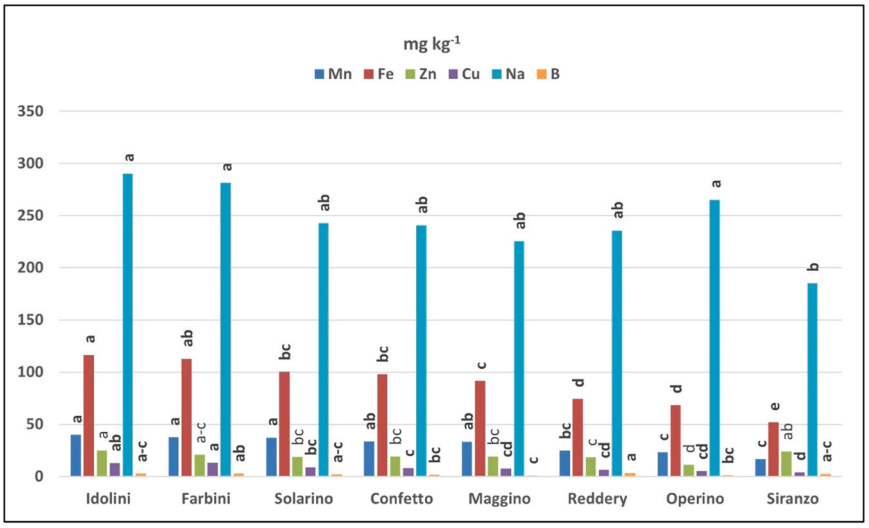

Fig. 5. Micro element manganese (Mn), iron (Fe), zinc (Zn), copper (Cu), sodium (Na) and boron (B) contents in fruit tissues of tomato cultivars.

Table 5
Macro element nitrogen (N), potassium (K), calcium (Ca), phosphorus (P), magnesium (Mg), sulfur (S) and micro element manganese (Mn), iron (Fe), zinc (Zn), copper (Cu), sodium (Na) and boron (B) contents, along with standard deviations in fruit tissues of tomato cultivars.

Cultivars	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (%)	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
Idolini	3.67	0.16	0.58	0.06	2.87	0.06	1.58	0.06	0.58	0.07	0.26	0.02
Farbini	3.62	0.05	0.37	0.01	2.62	0.12	1.53	0.07	0.40	0.03	0.25	0.01
Solarino	3.36	0.06	0.34	0.01	2.65	0.03	1.53	0.06	0.32	0.03	0.21	0.01
Confetto	3.23	0.07	0.47	0.01	2.39	0.12	1.60	0.06	0.31	0.01	0.21	0.01
Maggino	3.17	0.09	0.22	0.01	2.31	0.09	1.40	0.10	0.26	0.04	0.18	0.02
Reddery	2.34	0.29	0.25	0.01	1.89	0.33	1.21	0.10	0.23	0.04	0.17	0.02
Operino	2.14	0.20	0.17	0.01	1.57	0.15	1.05	0.09	0.20	0.01	0.16	0.01
Siranzo	1.60	0.01	0.16	0.01	1.26	0.03	0.76	0.06	0.15	0.01	0.11	0.01
Min	1.60		0.16		1.26		0.76		0.15		0.11	
Max	3.67		0.58		2.87		1.60		0.58		0.26	
Mean	2.89		0.32		2.20		1.33		0.31		0.19	
p value	0.000		0.000		0.000		0.000		0.000		0.000	
Cultivars	Mn (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		Cu (mg kg^{-1})		Na (mg kg^{-1})		B (mg kg^{-1})	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
Idolini	39.89	2.12	116.54	5.80	25.02	1.24	12.76	1.95	290.49	31.19	2.71	0.58
Farbini	37.67	2.35	112.9	1.75	20.72	1.03	13.08	1.86	281.44	28.35	2.77	0.70
Solarino	37.35	3.44	100.28	2.53	18.85	1.59	9.07	0.52	242.74	11.52	1.99	0.74
Confetto	33.47	1.99	98.15	3.82	19.32	2.29	8.06	1.02	240.76	5.25	1.68	0.85
Maggino	33.36	5.50	91.68	7.76	19.15	2.85	7.53	1.86	225.58	10.02	1.04	0.12
Reddery	24.72	4.77	74.36	9.27	18.33	2.2	6.49	0.95	235.73	25.58	3.46	0.27
Operino	23.35	0.32	68.51	4.77	11.46	0.56	5.31	0.93	265.27	56.13	1.12	0.62
Siranzo	16.81	0.61	52.12	3.29	23.88	1.66	4.14	1.06	185.07	12.07	2.66	0.51
Min	16.81		52.12		11.46		4.14		185.07		1.04	
Max	39.89		116.54		25.02		13.08		290.49		3.46	
Mean	30.83		89.32		19.59		8.31		245.89		2.18	
p value	0.000		0.000		0.000		0.000		0.006		0.001	

$\pm$ 2.12 mg kg^{-1} (Idolini), iron content was measured between 52.12 $\pm$ 3.29 mg kg^{-1} (Siranzo) and 116.54 $\pm$ 5.80 mg kg^{-1} (Idolini). Zinc content ranged from 11.46 $\pm$ 0.56 mg kg^{-1} (Operino) to 25.02 $\pm$ 1.24 mg kg^{-1} (Idolini), while copper content ranged from 4.14 $\pm$ 1.06 mg kg^{-1} (Siranzo) to 13.08 $\pm$ 1.86 mg kg^{-1} (Farbini). Sodium content was determined between 185.07 $\pm$ 12.07 mg kg^{-1} (Siranzo) and 290.49 $\pm$ 31.19 mg kg^{-1} (Idolini), while boron content was measured between 1.04 $\pm$ 0.12 mg kg^{-1} (Maggino) and 3.46 $\pm$ 0.27 mg kg^{-1} (Reddery). Significant differences were found between the cultivars at $p < 0.01$ level for boron and sodium content and at $p < 0.001$ level for other elements.

3.3. Hormones

The hormone contents of indole acetic acid (IAA), abscisic acid (ABA), gibberellic acid (GA), salicylic acid (SA), cytokinin, zeatin and jasmonic acid (JA) in fruit tissues of eight different tomato cultivars are compared in Fig. 6. Idolini cultivar has the highest IAA level compared to the other cultivars, and Operino cultivar is distinguished by its low IAA content. Operino was significantly different from the other cultivars in terms of ABA content and reached the highest value, while Idolini cultivar had the lowest ABA content. Idolini cultivar has a high value in terms of GA content compared to other cultivars. On the other hand, GA levels were quite low in Operino and Maggino cultivars. SA content was low in Operino cultivar and no significant differences were observed between it and the other cultivars. Reddery and Idolini cultivars had the

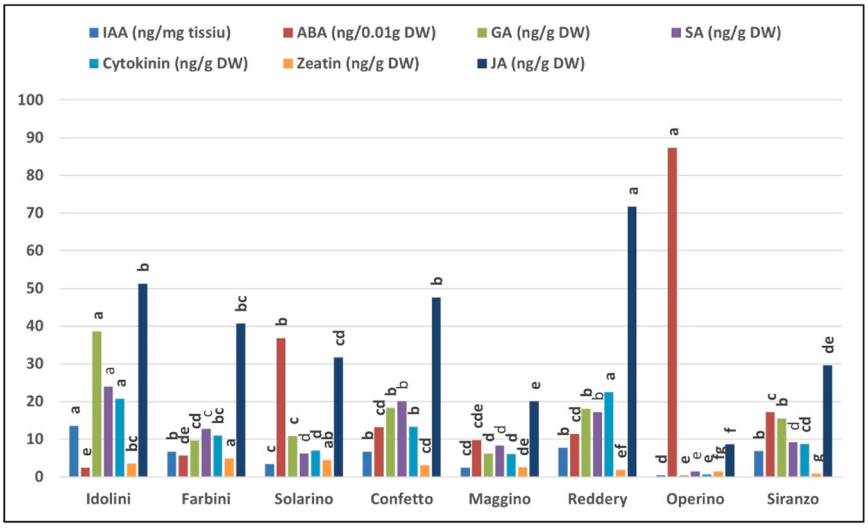

Fig. 6. Indole acetic acid (IAA), abscisic acid (ABA), gibberellic acid (GA), salicylic acid (SA), cytokinin, zeatin and jasmonic acid (JA) contents in fruit tissues of tomato cultivars.

highest levels of cytokinin content, while cytokinin levels were low in other cultivars. The Farbini cultivar stands out in terms of zeatin content, while the lowest zeatin levels were recorded in the Reddery, Siranzo and Operino cultivars. Finally, Reddery cultivar had the highest value in terms of JA content, while Siranzo cultivar had the lowest JA level.

The contents and standard deviations of hormone indole acetic acid (IAA), abscisic acid (ABA), gibberellic acid (GA), salicylic acid (SA), cytokinin, zeatin and jasmonic acid (JA) in fruit tissues of tomato cultivars are given in Table 6. IAA content in fruit tissues of the cultivars varied between 0.42 ± 0.10 ng/mg tissue (Operino) and 13.58 ± 1.20 ng/mg tissue (Idolini). ABA content ranged from 247.84 ± 44.07 ng/g DW (Idolini) to 8741.16 ± 534.64 ng/g DW (Operino). GA levels ranged from 0.43 ± 0.47 ng/g DW (Operino) to 38.61 ± 2.06 ng/g DW (Idolini). SA content ranged from 1.45 ± 0.08 ng/g DW (Operino) to 24.01 ± 2.36 ng/g DW (Idolini). Cytokinin content varied between 0.66 ± 0.15 ng/g DW (Operino) and 22.49 ± 1.49 ng/g DW (Reddery). Zeatin content of the cultivars ranged from 0.93 ± 0.22 ng/g DW (Siranzo) to 4.87 ± 0.49 ng/g DW (Farbini). JA levels ranged from 8.62 ± 0.52 ng/g DW (Operino) to 71.72 ± 6.39 ng/g DW (Reddery). These results revealed that the hormone contents in fruit tissues of different tomato cultivars differed significantly among the cultivars ($p < 0.001$).

3.4. Organic acids

The concentrations (ng μg^{-1}) of oxalic acid, propionic acid, tartaric acid, butyric acid, malonic acid and malic acid in the fruit tissues of eight tomato cultivars are given in Fig. 7. Oxalic acid content was highest in Idolini cultivar and lowest in Confetto and Farbini cultivars. No difference was observed between the cultivars in terms of propionic acid content. Tartaric acid content was highest in Idolini cultivar and lowest in Farbini cultivar. Butyric acid content was highest in Idolini and Confetto cultivars and lowest in Siranzo cultivar. Malonic acid content was highest in Reddery cultivar and lowest in Farbini, Maggino, Operino and Solarino cultivars. Malic acid was highest in the fruit tissues of Reddery and Siranzo cultivars and lowest in Farbini and Solarino cultivars.

Lactic acid, citric acid, maleic acid, fumaric acid and succinic acid (ng μg^{-1}) contents in the fruit tissues of eight tomato cultivars are shown in Fig. 8. Lactic acid, citric acid, maleic acid and fumaric acid contents were highest in Reddery cultivar compared to other cultivars, while succinic acid content was highest in Confetto cultivar. The lowest lactic acid content was determined in Farbini, citric acid in Solarino, fumaric and succinic acid in Solarino.

The mean values (Mean), standard deviations (StDev) and statistical significance levels (p-values) for organic acids of the cultivars are given in Table 7. Oxalic acid content in fruit tissues of the cultivars ranged from 13.03 ± 2.78 ng μg^{-1} (Farbini) to 25.16 ± 4.98 ng μg^{-1} (Idolini), while propionic acid content ranged from 14.33 ± 3.25 ng μg^{-1} (Farbini) to 24.81 ± 1.98 ng μg^{-1} (Operino). The tartaric acid content ranged from 11.62 ± 1.15 ng μg^{-1} (Farbini) to 21.20 ± 3.80 ng μg^{-1} (Idolini), butyric acid content ranged from 15.19 ± 1.22 ng μg^{-1} (Siranzo) to 34.85 ± 9.93 ng μg^{-1} (Idolini), malonic acid content ranged from 22.63 ± 4.76 ng μg^{-1} (Farbini) to 61.56 ± 9.97 ng μg^{-1} (Reddery) and malic acid content ranged from 9.34 ± 2.04 ng μg^{-1} (Farbini) to 20.43 ± 3.31 ng μg^{-1} (Reddery). Lactic acid content of tomato cultivars ranged from 16.62 ± 2.10 ng μg^{-1} (Farbini) to 29.83 ± 4.83 ng μg^{-1} (Reddery). Citric acid content of the cultivars ranged from 16.89 ± 2.68 ng μg^{-1} (Solarino) to 30.02 ± 4.86 ng μg^{-1} (Reddery), maleic acid from 6.95 ± 1.46 ng μg^{-1} (Solarino) to 29.83 ± 4.83 ng μg^{-1} (Reddery), fumaric acid 16.56 ± 2.77 ng μg^{-1} (Solarino) to 26.71 ± 4.79 ng μg^{-1} (Idolini) and succinic acid ranged from 20.03 ± 1.47 ng μg^{-1} (Solarino) to 40.40 ± 5.91 ng μg^{-1} (Confetto). The effect of cultivars on malonic acid, malic acid, lactic acid, fumaric acid and succinic acid content in fruit tissues $p < 0.001$, on oxalic acid, butric acid content $p < 0.01$ and on tartatric acid, citric acid, maleic acid content $p < 0.05$. The effect of cultivars on proponic acid content was not statistically significant ($p > 0.05$).

3.5. Amino acids

The amino acid concentrations (pmol μL^{-1}) of aspartate, glutamate, asparagine, serine, glutamine and histidine of tomato cultivars are given

Table 6
Indole acetic acid (IAA), abscisic acid (ABA), gibberellic acid (GA), salicylic acid (SA), cytokinin, zeatin and jasmonic acid (JA) contens, along with standard deviations in fruit tissues of tomato cultivars.

Cultivars	IAA (ng/mg tissue)		ABA (ng/g DW)		GA (ng/g DW)		SA (ng/g DW)	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
Idolini	13.58	1.20	247.84	44.07	38.61	2.06	24.01	2.36
Farbini	6.61	0.27	569.16	46.14	9.64	0.19	12.78	0.40
Solarino	3.42	0.19	3684.58	41.23	10.88	0.90	6.20	0.88
Confetto	6.70	0.24	1318.40	267.36	18.3	1.14	20.13	1.29
Maggino	2.47	0.31	975.13	11.83	6.20	0.22	8.31	0.87
Reddery	7.77	1.25	1140.71	140.45	18.07	0.99	17.17	0.86
Operino	0.42	0.10	8741.16	534.64	0.43	0.47	1.45	0.08
Siranzo	6.87	1.67	1723.30	626.74	15.54	2.19	9.26	0.34
Min	0.42		247.84		0.43		1.45	
Max	13.58		8741.16		38.61		24.01	
Means	5.98		2300.04		14.71		12.41	
p value	0.000		0.000		0.000		0.000	
Cultivars	Cytokinin (ng/g DW)		Zeatin (ng/g DW)		JA (ng/g DW)			
	Mean	StDev	Mean	StDev	Mean	StDev		
Idolini	20.73	1.38	3.60	0.40	51.26	0.60		
Farbini	10.96	0.49	4.87	0.49	40.67	1.15		
Solarino	7.05	0.66	4.42	0.05	31.67	7.30		
Confetto	13.28	2.06	3.11	0.46	47.61	2.06		
Maggino	6.10	0.67	2.61	0.14	20.11	1.80		
Reddery	22.49	1.49	1.90	0.28	71.72	6.39		
Operino	0.66	0.15	1.48	0.32	8.62	0.52		
Siranzo	8.73	0.78	0.93	0.22	29.65	2.95		
Min	0.66		0.93		8.62			
Max	22.49		4.87		71.72			
Means	11.25		2.87		37.66			
p value	0.000		0.000		0.000			

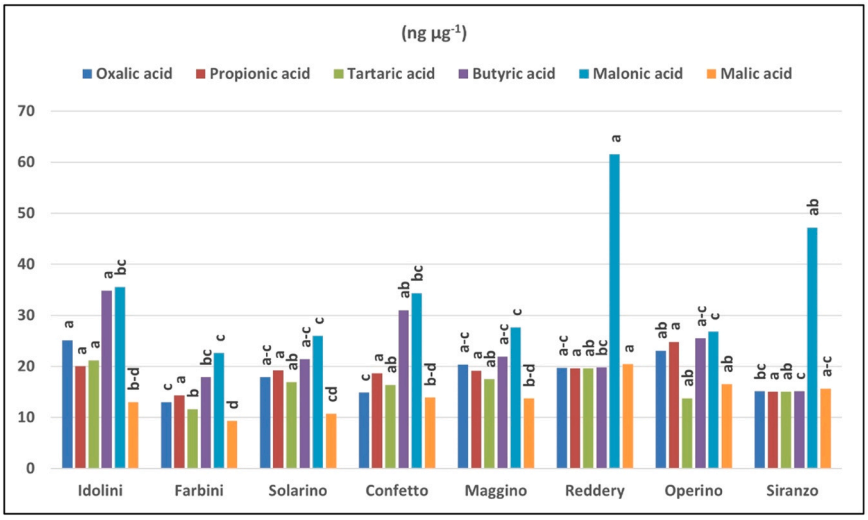

Fig. 7. Oxalic acid, propionic acid, tartaric acid, butyric acid, malonic acid and malic acid contents in fruit tissues of tomato cultivars.

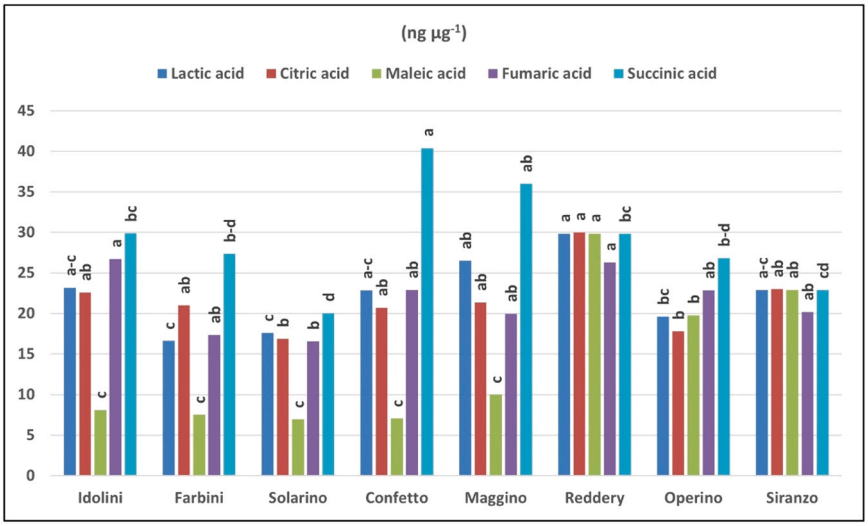

Fig. 8. Lactic acid, citric acid, maleic acid, fumaric acid and succinic acid contents in fruit tissues of tomato cultivars.

in Fig. 9. While the highest aspartate content was determined in Idolini cultivar, the lowest aspartate content was observed in Siranzo cultivar. The highest glutamate content was determined in Reddery cultivar, while the lowest was observed in Idolini, Solarino, Maggino and Operino cultivars. Asparagine content was highest in Idolini, Farbini, Confetto and Operino cultivars and lowest in Siranzo cultivar. Serine content was highest in Confetto cultivar and lowest in Siranzo cultivar. The highest glutamine content in fruit tissues was determined in Reddery cultivar, while the lowest was observed in Idolini and Solarino cultivars. Histidine amino acid content was highest in Reddery cultivar and lowest in Operino cultivar.

The amino acid concentrations (pmol µL-^{1}) of glycine, threonine, arginine, alanine, tyrosine and cystine of tomato cultivars are shown in Fig. 10. The highest glycine content was determined in Reddery cultivar while the lowest was observed in Solarino cultivar. Threonine was highest in Reddrey cultivar and lowest in Farbini and Solarino cultivars. Alanine was highest in Confetto cultivar and lowest in Operino cultivar. Tyrosine content was highest in Idolini cultivar and lowest in Siranzo cultivar. Cystine content was highest in Confetto cultivar and lowest in Operino cultivar.

Concentrations (pmol µL-^{1}) of valine, methionine, tryptophan, phenylalanine and isoleucine amino acids of tomato cultivars are shown in Fig. 11. Valine content was highest in Confetto cultivar and lowest in Idolini and Siranzo cultivars. Methionine content was highest in Reddery cultivar. Tryptophan content was highest in Maggino cultivar and lowest in Solarino cultivar. Phenylalanine content was highest in Idolini cultivar and lowest in Siranzo cultivar. Isoleucine was highest in Confetto cultivar and lowest in Idolini and Operino cultivars.

Concentrations (pmol µL^{-1}) of leucine, lysine, hydroxyproline, sarcosine and proline amino acids of tomato cultivars are shown in Fig. 12. The highest leucine content was determined in Reddery cultivar, while the lowest was determined in Idolini, Maggino and Operino cultivars. The highest levels of hydroxyproline and proline amino acids were determined in Reddery cultivar. The lowest hydroxyproline and proline content was determined in Idolini cultivar. There was no statistically significant effect of cultivars on sarcosine content. The highest lysine content was determined in Confetto cultivar.

The aspartate content of tomato cultivars ranged from 273.66 pmol/µL (Siranzo) to 558.63 pmol/µL (Idolini), while glutamate content ranged from 169.91 pmol/µL (Idolini) to 440.77 pmol/µL (Reddery). Asparagine content ranged from 192.99 pmol/µL (Siranzo) to 416.66 pmol/µL (Farbini), while serine content ranged from 175.84 pmol/µL (Siranzo) to 535.25 pmol/µL (Confetto). Glutamine content ranged from 139.75 pmol/µL (Solarino) to 308.56 pmol/µL (Reddery), while

Table 7
Oxalic acid, propionic acid, tartaric acid, butyric acid, malonic acid, malic acid, lactic acid, citric acid, maleic acid, fumaric acid and succinic acid contents, along with standard deviations in fruit tissues of tomato cultivars.

Cultivar	Oxalic acid (ng μg^{-1})		Propionic acid (ng μg^{-1})		Tartaric acid (ng μg^{-1})		Butyric acid (ng μg^{-1})		Malonic acid (ng μg^{-1})		Malic acid (ng μg^{-1})	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
Idolini	25.16	4.98	20.02	6.72	21.2	3.80	34.85	9.93	35.55	6.12	13.05	0.81
Farbini	13.03	2.78	14.33	3.25	11.62	1.15	17.91	2.89	22.63	4.76	9.34	2.04
Solarino	17.89	2.04	19.24	2.30	16.93	3.09	21.42	5.10	26.00	3.62	10.76	0.86
Confetto	14.88	1.79	18.66	5.43	16.38	0.61	31.03	4.30	34.37	9.08	13.92	1.38
Maggino	20.39	3.32	19.14	2.00	17.49	5.03	21.96	4.31	27.68	3.99	13.73	3.42
Reddery	19.73	3.20	19.62	3.18	19.62	3.18	19.8	3.21	61.56	9.97	20.43	3.31
Operino	23.1	1.08	24.81	1.98	13.78	2.01	25.5	1.12	26.84	7.88	16.52	0.24
Siranzo	15.13	1.22	15.05	1.21	15.05	1.21	15.19	1.22	47.22	3.80	15.67	1.26
Min	13.03		14.33		11.62		15.19		22.63		9.34	
Max	25.16		24.81		21.20		34.85		61.56		20.43	
Means	18.66		18.86		16.51		23.46		35.23		14.18	
p value	0.001		0.083		0.020		0.002		0.000		0.000	
Cultivar	Lactic acid (ng μg^{-1})		Citric acid (ng μg^{-1})		Maleic acid (ng μg^{-1})		Fumaric acid (ng μg^{-1})		Succinic acid (ng μg^{-1})			
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev		
Idolini	23.18	1.67	22.58	3.70	8.12	1.69	26.71	4.79	29.88	1.84		
Farbini	16.62	2.10	20.98	1.71	7.51	3.52	17.34	1.36	27.36	1.85		
Solarino	17.60	1.22	16.89	2.68	6.95	1.46	16.56	2.77	20.03	1.47		
Confetto	22.83	4.26	20.69	4.15	7.06	0.69	22.89	5.59	40.40	5.91		
Maggino	26.49	2.40	21.36	7.18	9.99	2.21	19.97	1.57	35.99	3.64		
Reddery	29.83	4.83	30.02	4.86	29.83	4.83	26.29	4.26	29.83	4.83		
Operino	19.64	1.04	17.81	4.50	19.77	0.98	22.83	1.99	26.83	1.28		
Siranzo	22.88	1.84	23.03	1.85	22.88	1.84	20.17	1.62	22.88	1.84		
Min	16.62		16.89		6.95		16.56		20.03			
Max	29.83		30.02		29.83		26.71		40.40			
Means	22.38		21.67		14.01		21.60		29.15			
p value	0.000		0.045		0.013		0.000		0.000			

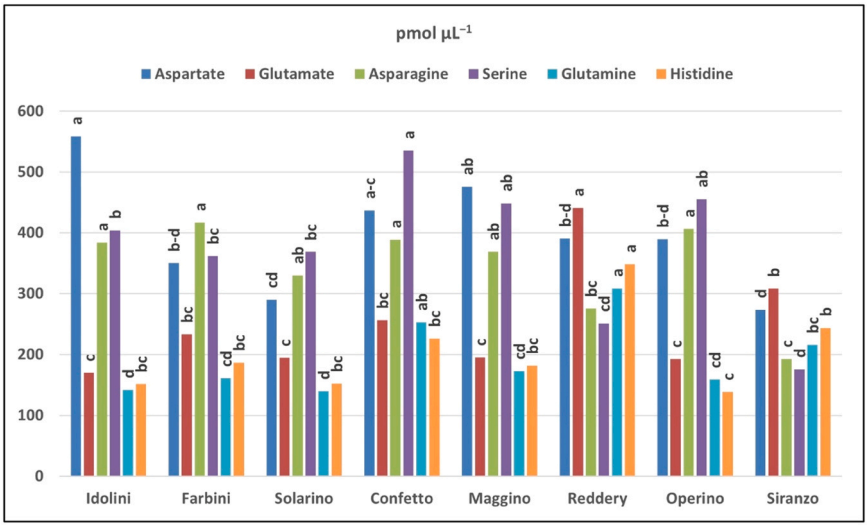

Fig. 9. Amino acid concentrations of aspartate, glutamate, asparagine, serine, glutamine and histidine in fruit tissues of tomato cultivars.

histidine content ranged from 138.93 pmol/μL (Operino) to 348.20 pmol/μL (Reddery). Glycine content ranged from 164.65 pmol/μL (Solarino) to 401.59 pmol/μL (Reddery), while threonine content ranged from 174.47 pmol/μL (Solarino) to 453.83 pmol/μL (Reddery). Arginine content ranged from 275.14 pmol/μL (Siranzo) to 439.73 pmol/μL (Confetto), alanine content ranged from 110.62 pmol/μL (Operino) to 654.42 pmol/μL (Confetto), tyrosine content ranged from 192.30 pmol/μL (Siranzo) to 621.12 pmol/μL (Idolini), cystine content ranged from 150.44 pmol/μL (Operino) to 275.26 pmol/μL (Confetto). The effect of cultivars on other amino acids except arginine and cystine was significant at $p < 0.001$ level (Table 8, Table 9).

Valine content in fruit tissues of tomato cultivars ranged from 185.43 pmol/μL (Idolini) to 306.00 pmol/μL (Confetto), methionine content ranged from 170.52 pmol/μL (Operino) to 345.74 pmol/μL (Reddery). Tryptophan content ranged from 184.29 pmol/μL (Solarino) to 477.76 pmol/μL (Maggino), phenylalanine content from 319.60 pmol/μL (Siranzo) to 900.08 pmol/μL (Idolini), isoleucine content 123. 78 pmol/μL (Operino) to 489.35 pmol/μL (Confetto), leucine content 127.55 pmol/μL (Idolini) to 399.96 pmol/μL (Reddery), lysine content 192. 30 pmol/μL (Siranzo) to 824.77 pmol/μL (Confetto), hydroxyproline content 128.62 pmol/μL (Idolini) to 251.71 pmol/μL (Reddery), sarcosine content 217. 67 pmol/μL (Siranzo) to 404.53 pmol/μL (Confetto), proline content ranged from 131.75 pmol/μL (Idolini) to 301.45 pmol/μL (Reddery) (Table 9).

3.6. Other contents

Glucose, fructose, sucrose and lycopene (mg 100 g^{-1} FW) contents in fruit tissues of eight different tomato cultivars are given in Fig. 13. Among the tomato cultivars, the highest gluocose content was

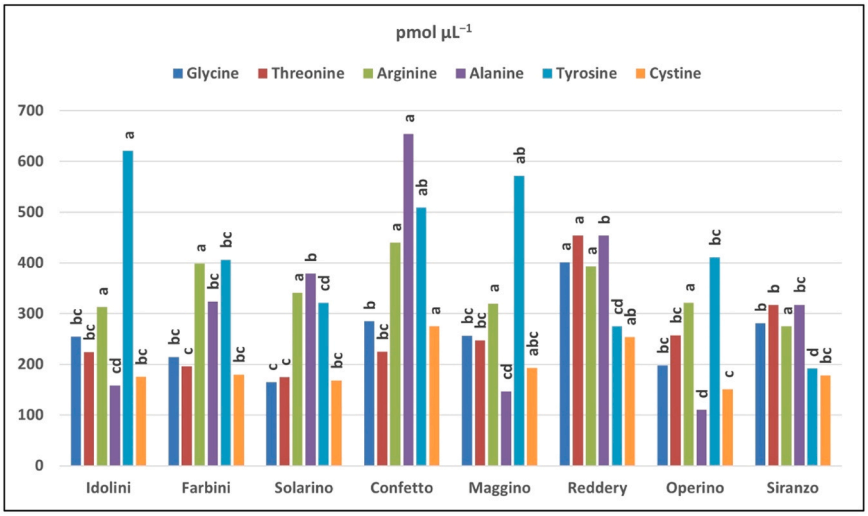

Fig. 10. Amino acid concentrations of glycine, threonine, arginine, alanine, tyrosine and cystine in fruit tissues of tomato cultivars.

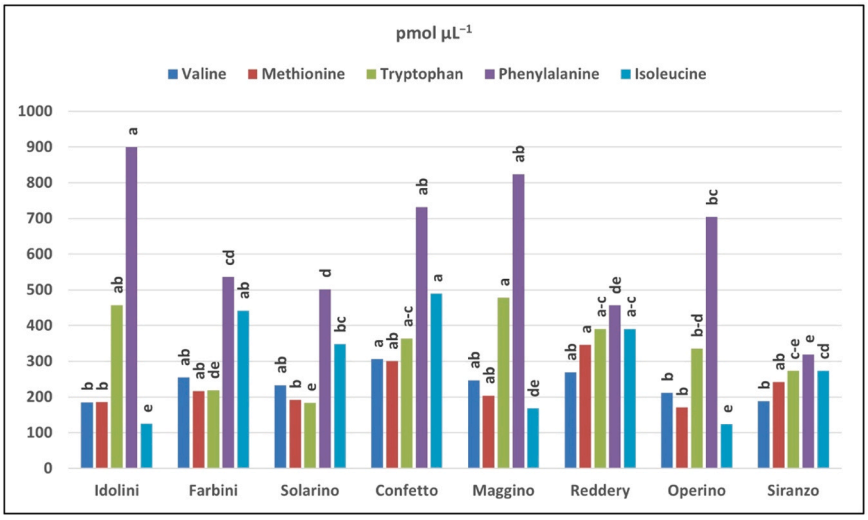

Fig. 11. Amino acid concentrations of valine, methionine, tryptophan, phenylalanine and isoleucine in fruit tissues of tomato cultivars.

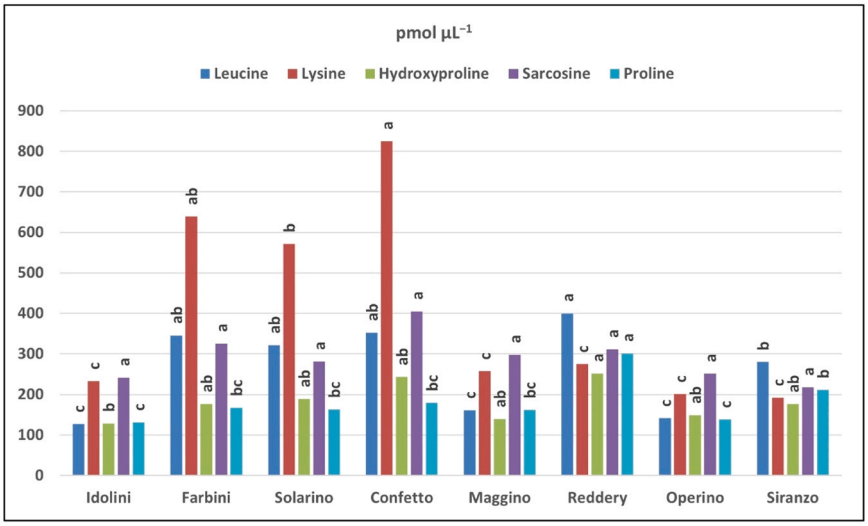

Fig. 12. Amino acid concentrations of leucine, lysine, hydroxyproline, sarcosine and proline in fruit tissues of tomato cultivars.

Table 8
Aspartate, glutamate, asparagine, serine, glutamine, glycine, threonine, arginine, alanine, tyrosine and cystine contents, along with standard deviations in fruit tissues of tomato cultivars.

Cultivar	Aspartate (pmol µL^{-1})		Glutamate (pmol µL^{-1})		Asparagine (pmol µL^{-1})		Serine (pmol µL^{-1})		Glutamine (pmol µL^{-1})		Histidine (pmol µL^{-1})	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
Idolini	558.63	30.42	169.91	16.35	383.82	14.44	403.87	49.75	141.95	5.85	151.69	8.35
Farbini	350.33	107.19	233.20	1.47	416.66	18.14	362.05	47.33	161.03	23.73	186.87	8.61
Solarino	290.26	66.33	194.59	29.43	329.77	3.26	368.63	14.94	139.75	13.39	152.25	30.84
Confetto	436.93	16.87	256.26	72.06	388.61	67.24	535.25	54.47	252.92	13.40	226.55	68.69
Maggino	475.76	17.96	195.53	3.64	368.84	46.09	448.70	77.07	173.15	17.07	181.89	22.85
Reddery	391.04	63.13	440.77	71.16	275.77	44.52	251.26	40.56	308.56	49.81	348.20	56.21
Operino	389.77	10.35	192.68	16.21	406.29	33.15	455.53	4.64	158.91	11.01	138.93	15.68
Siranzo	273.66	28.88	308.46	32.55	192.99	20.37	175.84	18.56	215.94	22.79	243.68	25.72
Min	273.66		169.91		192.99		175.84		139.75		138.93	
Max	558.63		440.77		416.66		535.25		308.56		348.20	
Means	395.80		248.93		345.34		375.14		194.03		203.76	
p value	0.000		0.000		0.000		0.000		0.000		0.000	
Cultivar	Glycine (pmol µL^{-1})		Threonine (pmol µL^{-1})		Arginine (pmol µL^{-1})		Alanine (pmol µL^{-1})		Tyrosine (pmol µL^{-1})		Cystine (pmol µL^{-1})	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
Idolini	254.20	56.02	223.68	17.67	313.35	20.49	158.26	5.28	621.12	35.24	175.44	16.08
Farbini	214.63	41.72	195.73	32.10	398.74	79.73	323.96	150.81	406.34	139.24	179.76	17.85
Solarino	164.65	4.89	174.47	32.96	340.82	58.45	379.43	7.75	321.04	36.07	167.80	37.24
Confetto	284.95	33.70	224.66	18.65	439.73	128.95	654.42	97.84	509.01	41.74	275.26	60.28
Maggino	256.02	12.45	246.91	57.17	319.67	100.71	146.73	24.51	572.22	51.65	192.81	18.24
Reddery	401.59	64.83	453.83	73.27	393.15	63.47	453.83	73.27	274.78	44.36	253.97	41.00
Operino	197.80	30.71	257.33	8.95	320.97	32.54	110.62	3.35	410.95	5.38	150.44	1.53
Siranzo	281.04	29.66	317.60	33.52	275.14	29.04	317.60	33.52	192.30	20.29	177.74	18.76
Min	164.65		174.47		275.14		110.62		192.30		150.44	
Max	401.59		453.83		439.73		654.42		621.12		275.26	
Means	256.86		261.78		350.20		318.11		413.47		196.65	
p value	0.000		0.000		0.183		0.000		0.000		0.002	

Table 9
Valine, methionine, tryptophan, phenylalanine, isoleucine, leucine, lysine, hydroxyproline, sarcosine and proline contents, along with standard deviations in fruit tissues of tomato cultivars.

Cultivar	Valine (pmol µL^{-1})		Methionine (pmol µL^{-1})		Tryptophan (pmol µL^{-1})		Phenylalanine (pmol µL^{-1})		Isoleucine (pmol µL^{-1})	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
Idolini	185.43	31.67	185.65	6.34	457.28	36.2	900.08	30.87	125.09	19.19
Farbini	254.52	26.07	216.46	42.03	219.33	30.11	536.13	11.32	441.93	16.62
Solarino	233.44	33.46	191.62	38.51	184.29	12.57	502.05	48.13	348.35	40.96
Confetto	306.00	25.94	300.31	115.79	363.93	80.95	732.18	78.84	489.35	81.67
Maggino	246.82	47.69	203.82	34.20	477.76	23.97	823.92	129.23	168.16	25.55
Reddery	269.27	43.47	345.74	55.82	391.04	63.13	456.68	73.73	391.04	63.13
Operino	211.73	3.83	170.52	20.65	335.85	25.91	704.30	5.85	123.78	5.03
Siranzo	188.44	19.89	241.96	25.53	273.66	28.88	319.60	33.73	273.66	28.88
Min	185.43		170.52		184.29		319.60		123.78	
Max	306.00		345.74		477.76		900.08		489.35	
Means	236.96		232.01		337.89		621.87		295.17	
p value	0.000		0.000		0.000		0.000		0.000	
Cultivar	Leucine (pmol µL^{-1})		Lysine (pmol µL^{-1})		Hydroxyproline (pmol µL^{-1})		Sarcosine(pmol µL^{-1})		Proline (pmol µL^{-1})	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
Idolini	127.55	3.68	233.23	6.81	128.62	3.64	241.33	25.24	131.75	22.76
Farbini	345.54	20.64	638.78	5.44	176.74	57.51	325.47	74.18	167.76	16.05
Solarino	321.35	18.76	571.20	1.48	189.11	56.74	281.16	60.12	163.21	20.61
Confetto	352.53	25.99	824.77	200.46	242.99	63.05	404.53	173.5	179.78	21.21
Maggino	161.44	42.17	257.35	76.33	139.25	24.79	297.96	2.87	162.15	22.07
Reddery	399.96	64.57	274.78	44.36	251.71	40.64	311.04	50.21	301.45	48.67
Operino	141.60	11.14	201.17	21.40	148.49	4.49	251.14	25.46	138.57	8.36
Siranzo	279.90	29.54	192.30	20.29	176.15	18.59	217.67	22.97	210.96	22.26
Min	127.55		192.30		128.62		217.67		131.75	
Max	399.96		824.77		251.71		404.53		301.45	
Means	266.23		399.20		181.63		291.29		181.95	
p value	0.000		0.000		0.000		0.137		0.000	

determined in Solarino cultivar, while the lowest was determined in Reddery and Operino cultivars. The highest fructose content was also determined in Solarino cultivar. The highest sucrose content was measured in Siranzo cultivar, while the lowest was measured in Farbini, Maggino and Reddery cultivars. The highest lycopene content was measured in the red-colored Confetto and Idolini cultivars, while the lowest was determined in the yellow-colored Maggino cultivar.

Total sugar content in fruit tissues of tomato cultivars was highest in Confetto cultivar and lowest in Reddery cultivar. The highest total organic acid content (mg/1000 g FW) was measured in Solarino cultivar and the lowest in Confetto and Operino cultivars. Total phenolic content was highest in Idolini and Reddery cultivars and lowest in Maggino cultivar. Total flavonoid content (mg CE/g DW) was highest in Idolini cultivar and lowest in Siranzo cultivar. Vitamin C (mg/100 FW) was highest in Idolini, Farbini and Solarino cultivars and lowest in Confetto cultivar. Antioxidant activity (%) was highest in Idolini cultivar and

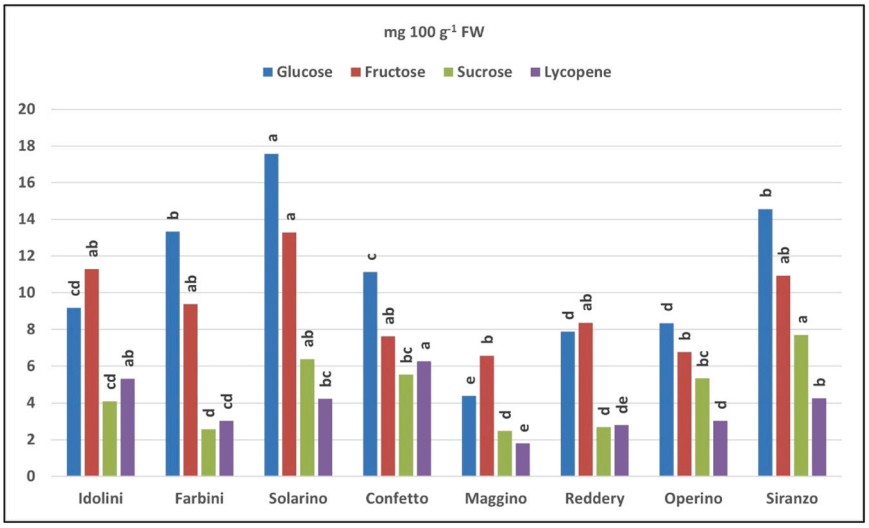

Fig. 13. Glucose, fructose, sucrose and lycopene contents in fruit tissues of tomato cultivars.

lowest in Siranzo cultivar (Fig. 14).

Glucose (mg 100 g^{-1} FW) 4.39 ± 0.38 (Maggino) to 17.58 ± 0.95 (Solarino), fructose (mg 100 g^{-1} FW) 6.57 ± 1.13 (Maggino) to 13.29 ± 1.56 (Solarino), sucrose (mg 100 g^{-1} FW) 2.48 ± 0. 17 (Maggino) to 7.69 ± 0.84 (Siranzo), total sugar (mg 100 g^{-1} FW) ranged from 1340.70 ± 88.30 (Reddery) to 1840.10 ± 46.10 (Confetto), lycopene (mg 100 g^{-1} FW) ranged from 1.79 ± 0.21 (Maggino) to 6.27 ± 0.45 (Confetto). Total organic acid (mg 100 g^{-1} FW) ranged from 475.60 ± 18.00 (Operino) to 842.20 ± 43.40 (Solarino), total phenolic (mg GAE g^{-1} DW) ranged from 42.41 ± 2.08 (Maggino) to 63.59 ± 1.15 (Reddery), total flavonoid (mg CE g^{-1} DW) ranged from 44.39 ± 1. 65 (Siranzo) to 109.16 ± 5.43 (Idolini), vitamin C (mg 100 g^{-1} FW) ranged from 62.85 ± 2.58 (Siranzo) to 102.46 ± 4.31 (Idolini), antioxidant activity (%) ranged from 52.69 ± 2.85 (Siranzo) to 95.45 ± 1.64 (Idolini). The effect of tomato cultivars on glucose, sucrose, lycopene, total organic acid total phenolic total flavonoid vitamin c antioxidant activity content was $p < 0.001$, while the effect on fructose content was $p < 0.01$ (Table 10).

3.7. Principal component analysis

A detailed analysis of the PCA (Principal Component Analysis) results of the phytochemical components in the fruit tissues of 8 different tomato cultivars is presented in Fig. 15. According to the analysis, two principal components (33.10 % according to PC1 and 23.80 % according to PC2) explain about 57 % of the total variation. Idolini and Confetto cultivars with red fruits were the most rich in phytochemicals (phytonutrients, hormones, amino acids, vitamin C, lycopene) in region I of the graph, while Siranzo cultivar was the least rich in these phytochemicals. Siranzo cultivar had the highest amount of sucrose in its fruit tissues. The cultivar Reddery, which is located in Region II of the graph, had the highest amount of phytochemicals in Region II of the graph in its fruit tissues, while the cultivar Reddery had the lowest amount of phytochemicals in Regions IV of the graph. The yellow and yellow-orange Maggino and Operino cultivars in Region IV of the graph were the cultivars with the highest ABA hormone in their tissues. The Solarino cultivar in Region IV of the graph was the cultivar with the highest total organic acids, total flavonoids and antioxidant activity in its tissues. As seen in the graph, the cultivars with the lowest phytochemical content in their tissues were Siranzo, which has the highest average fruit weight, and Maggino and Operino cultivars with yellow and yellow-orange fruit color. The cultivars with the highest phytochemical content in their tissues were Idolini, Confetto and Reddery cultivars located in the I. and II. region of the graph.

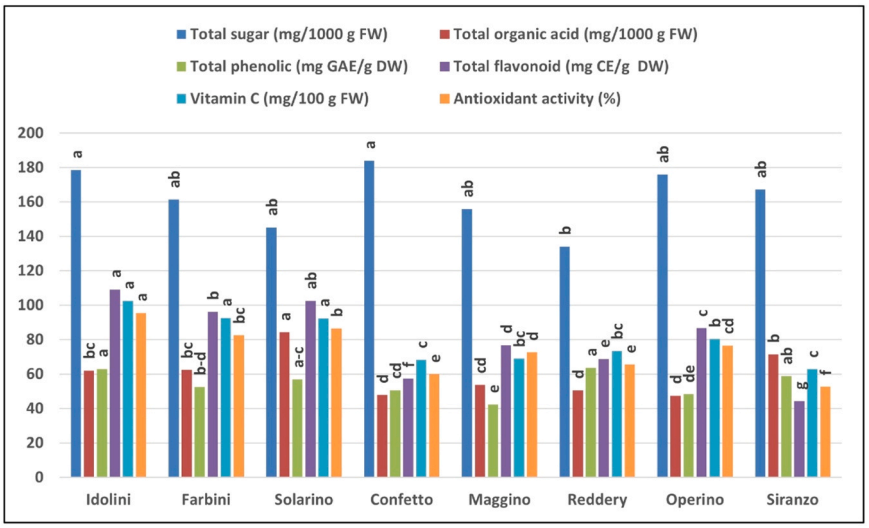

Fig. 14. Total sugar, total organic acid, total phenolic, total flavonoid, vitamin C and antioxidant activity contents in fruit tissues of tomato cultivars.

Table 10
Glucose, fructose, sucrose, lycopene total sugar, total organic acid, total phenolic, total flavonoid, vitamin C and antioxidant activity contens, along with standard deviations in fruit tissues of tomato cultivars.

Cultivar	Glucose (mg 100 g^{-1} FW)		Fructose (mg 100 g^{-1} FW)		Sucrose (mg 100 g^{-1} FW)		Total Sugar (mg 100 g^{-1} FW)		Lycopene (mg 100 g^{-1} FW)	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
Idolini	9.18	0.47	11.29	4.93	4.10	0.41	1785.10	120.70	5.32	0.87
Farbini	13.33	0.38	9.38	0.65	2.58	0.22	1613.00	251.00	3.02	0.21
Solarino	17.58	0.95	13.29	1.56	6.39	0.47	1452.00	254.00	4.23	0.29
Confetto	11.13	0.98	7.63	1.80	5.53	1.49	1840.10	46.10	6.27	0.45
Maggino	4.39	0.38	6.57	1.13	2.48	0.17	1558.80	116.10	1.79	0.21
Reddery	7.89	0.38	8.37	0.43	2.68	0.15	1340.70	88.30	2.79	0.21
Operino	8.35	0.74	6.76	0.89	5.33	0.36	1758.50	121.70	3.02	0.37
Siranzo	14.57	1.09	10.93	0.73	7.69	0.84	1671.20	75.00	4.24	0.38
Min	4.39		6.57		2.48		1340.70		1.79	
Max	17.58		13.29		7.69		1840.10		6.27	
Means	10.80		9.28		4.60		1627.43		3.84	
P value	0.000		0.009		0.000		0.012		0.000	
Cultivar	Total Organic Acid (mg 100 g^{-1} FW)		Total Phenolic (mg GAE g^{-1} DW)		Total Flavonoid (mg CE g^{-1} DW)		Vitamin C (mg 100 g^{-1} FW)		Antioxidant Activity (%)	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
Idolini	621.10	37.10	63.06	2.61	109.16	5.43	102.46	4.31	95.45	1.64
Farbini	623.80	49.40	52.66	2.01	96.28	1.97	92.52	5.42	82.49	2.06
Solarino	842.20	43.40	56.94	1.83	102.47	2.80	92.30	3.60	86.38	1.00
Confetto	478.90	22.30	50.66	6.06	57.28	1.83	68.36	2.53	60.05	2.40
Maggino	537.30	28.30	42.41	2.08	76.84	1.80	69.00	5.14	72.67	2.99
Reddery	505.70	63.60	63.59	1.15	68.74	1.52	73.41	3.83	65.54	1.57
Operino	475.60	18.00	48.45	1.31	86.68	1.54	80.42	5.04	76.57	2.15
Siranzo	713.70	41.60	58.76	0.77	44.39	1.65	62.85	2.58	52.69	2.85
Min	475.60		42.41		44.39		62.85		52.69	
Max	842.20		63.59		109.16		102.46		95.45	
Means	599.79		54.57		80.23		80.17		73.98	
p value	0.000		0.000		0.000		0.000		0.000	

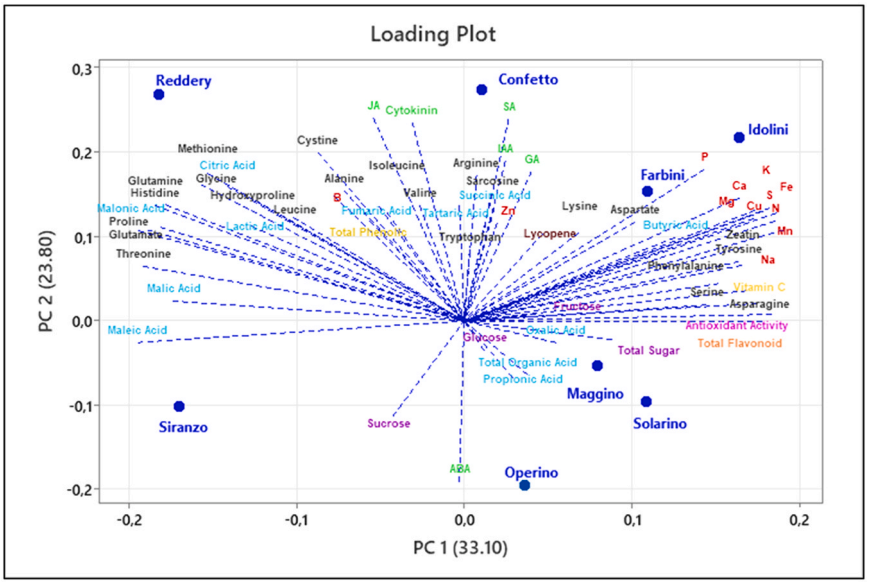

Fig. 15. Principal component analysis of phytochemical content in fruit tissues of tomato cultivars.

3.8. Heat map and correlations

62 phytochemical compounds in the fruit tissues in order to classify the cultivars with the highest, medium and lowest levels. The red Idolini cultivar has 34 phytochemical compounds at high level, 10 at medium level and 18 at low level in its fruit tissues, while the orange farbini cultivar has 20 compounds at high level, 18 at medium level and 24 at low level. The yellow fruit colored maggino cultivar contains 11 compounds at high level, 21 at medium level and 30 at low level. Operino cultivar with yellow-orange fruit color contains 7 compounds at high level, 14 at medium level and 41 at low level. The Siranzo cultivar with the highest average fruit weight contains 5 phytochemical compounds at high level, 27 at medium level and 30 at low level. Phytochemical contents of 8 different tomato cultivars in fruit tissues were evaluated and distinct groupings were made among the cultivars. The cultivars were divided into 3 main clusters in terms of phytochemical content and nutritional values. In the first main cluster, the Idolini cultivar was separated from all other cultivars and formed an independent cluster. Its prominent phytochemical characteristics are: malic acid, citric acid, vitamin C, total phenolic, antioxidant activity, fructose, sucrose Idolini is considered to have a remarkable sugar level in terms of taste profile. The second main cluster was divided into three subgroups: subcluster

one: Siranzo cultivar, subcluster two: Operino and Maggino, subcluster three: Solarino and Fabriini cultivars were placed in the same subcluster due to their similar phytochemical profiles. In the third main cluster, Reddery and Confetto were placed in a different main group from the other cultivars, although they had similar phytochemical characteristics. Idolini formed an independent cluster, indicating that this cultivar has a unique phytochemical structure. The subgroups in the second main cluster reflect the similarities and divergences between the cultivars. Reddery and Confetto stand out with their strong antioxidant properties. In the heat map graph created to show the relationship between the concentrations of chemical components in the fruit tissues of tomato cultivars, chemical contents were visualized. The graph is divided into two main groups. The first main group is divided into two subgroups. The first subgroup includes nitrogen, iron, calcium, manganese, phosphorus, zeatin, sulfur, copper, potassium, magnesium, fructose, lycopene, sucrose, sodium, total sugar, vitamin C and total organic acid. The second subgroup includes indole-3-acetic acid, gibberellic acid, salicylic acid, zinc, cytokinin, jasmonic acid, boron and glucose. The second main group is also divided into two subgroups. The first subgroup includes glutamate, histidine, proline, glutamine, glycine, threonine, malic acid, maleic acid, malonic acid, citric acid, lactic acid, methionine, hydroxyproline, cystine, sarcosine, isoleucine, leucine, alanine, arginine, valine, lysine and abscisic acid. The second subgroup includes asparagine, serine, tyrosine, phenylalanine, aspartate, tryptophan, succinic acid, oxalic acid, propionic acid, butyric acid, tartaric acid, fumaric acid, total flavonoids and antioxidant activity (Fig. 16).

The correlation matrix presented in Fig. 17 illustrates the associations among 62 phytochemical traits observed in fruit tissues of eight cultivars differing in fruit size and color (red, orange and yellow). A striking pattern emerges between fruit color and several key biochemical compounds. Yellow fruit color shows strong negative correlations with multiple secondary metabolites and phytohormones, such as total phenolics (r = -0.84), lycopene (r = -0.73), boron (r = -0.70), jasmonic acid (r = -0.70), gibberellic acid (r = -0.66), and indole-3-acetic acid (r = -0.66). These results suggest that red-colored fruits contain higher levels of these compounds. Furthermore, sugars and amino acids like fructose (r = -0.64), glucose (r = -0.58), alanine (r = -0.63), leucine (r = -0.54), and glutamate (r = -0.41) also displayed negative associations with yellow fruit color.Conversely, yellow-colored fruits showed positive correlations with amino acids such as asparagine (r = 0.42), phenylalanine (r = 0.38), serine (r = 0.37), and tyrosine (r = 0.35), indicating a distinct nitrogen metabolic profile compared to red fruits. These opposing patterns reinforce the idea that red fruits tend to accumulate higher levels of defense-related compounds and pigments, while yellow fruits may prioritize different biochemical pathways. Regarding average fruit weight, notable negative correlations were observed with asparagine (r = -0.79), calcium (r = -0.73), sodium (r = -0.70), serine (r = -0.69), manganese (r = -0.65), nitrogen (r = -0.65), total flavonoids (r = -0.63), potassium (r = -0.63), iron (r = -0.63), sulfur (r = -0.60), phenylalanine (r = -0.59), antioxidant activity (r = -0.59), tyrosine (r = -0.57), and several others. These findings suggest that larger fruits tend to have reduced levels of minerals and defense-related compounds. On the other hand, positive correlations with sucrose (r = 0.63), zinc (r = 0.47), maleic acid (r = 0.38), malonic acid (r = 0.37), glucose (r = 0.36), and total organic acids (r = 0.35) indicate that larger fruits may favor metabolic activities related to sugar

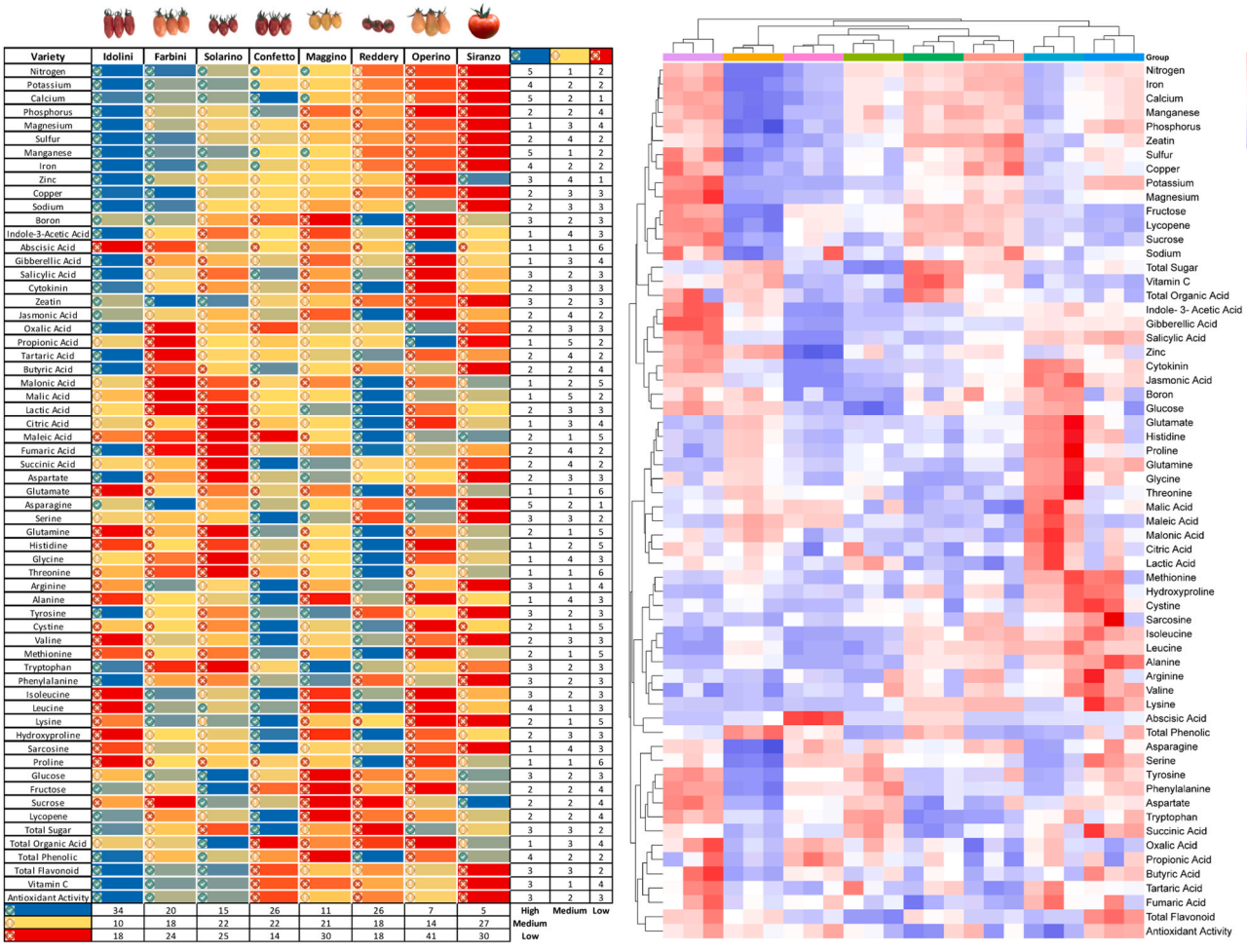

Fig. 16. Heat map of phytochemical content in fruit tissues of tomato cultivars.

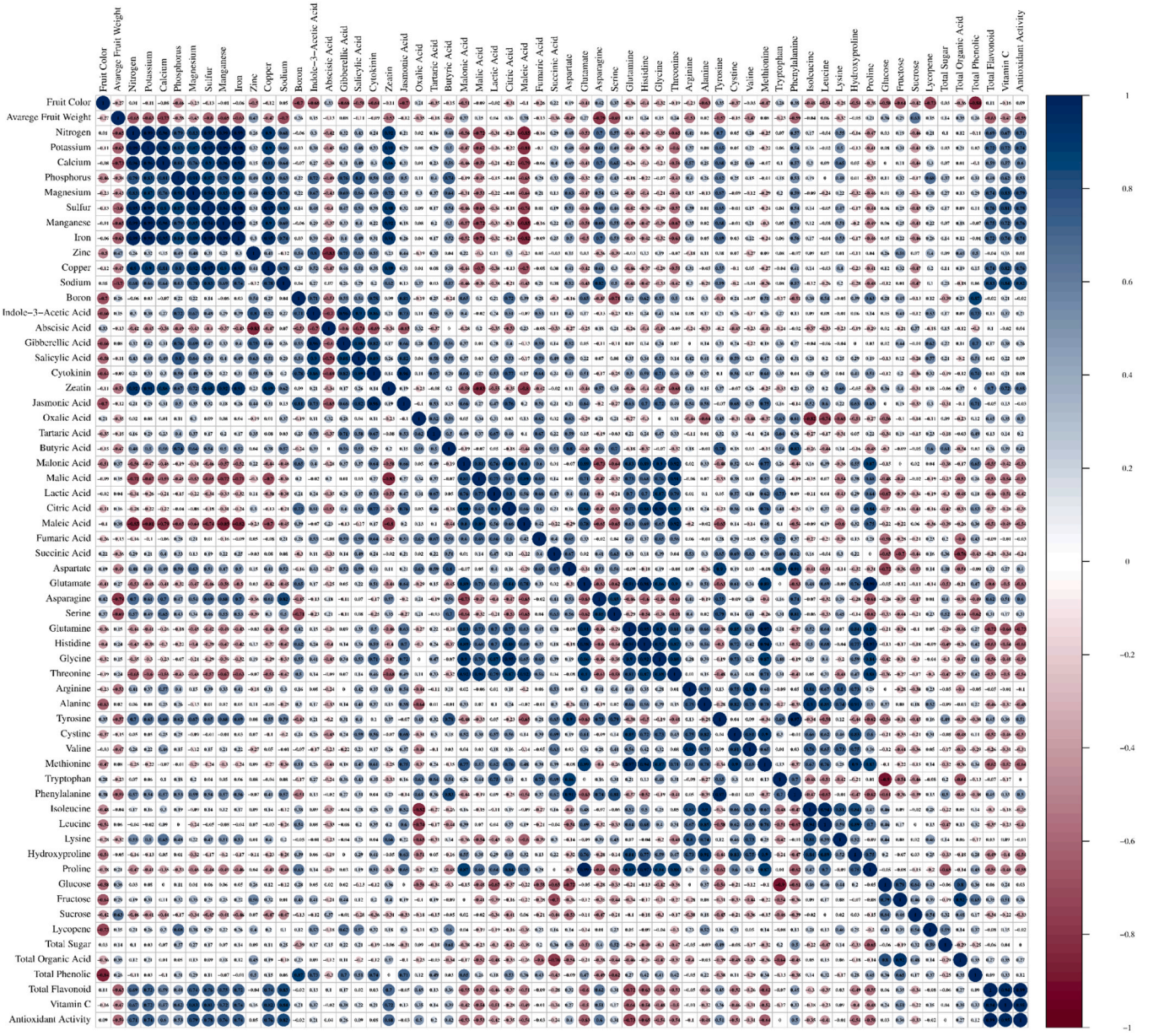

Fig. 17. Correlation between phytochemical contents in fruit tissues of tomato cultivars and fruit color and fruit weight.

accumulation, organic acid content, and energy metabolism.

4. Discussion

The Siranzo cultivar with its large fruit weight is advantageous for markets with large fruit demand, while the Solarino and Operino cultivars with small fruit weight are suitable for markets with compact fruit demand. The yellow colour of Maggino stands out for visually aesthetic preferences, while the cultivars with red colour (Idolini, Solarino, Confetto, Reddery, Siranzo) appeal to a wide audience for traditional consumption. The colour variations of Farbini and Operino may attract consumers looking for cultivar (Table 4). The results provide guidance for production planning and market strategies, and the selection of these cultivars in accordance with consumer demands has the potential to create agricultural added value. Colourful foods increase consumer demand as they evoke health, freshness and naturalness and play an important role in gastronomy trends with their visual appeal. In particular, social media influence contributes to colourful foods becoming a global fashion, reinforcing the perception of prestige and status (Bielaszka et al., 2024; Sarıışık and Kardeş, 2019).

In particular, sodium and iron contents were higher compared to other microelements, suggesting that tomato fruits may have a greater capacity to store these elements. However, all figures are within the range of other common tomatoes previously mentioned (Ali et al., 2020; Guil-Guerrero and Rebolloso-Fuentes, 2009). Statistically significant differences were found in macro and micro element contents among cultivars. This situation emphasizes the effects of the genetic structure of the cultivars on nutrient uptake and utilization. Especially red colored Idolini and orange colored Farbini cultivars stood out with their high macro and micro element contents. In addition, a negative correlation was found between high fruit weight and N, Mn, Na, Ca, K, Fe, S elements in fruit tissues. In other words, these nutrients were lower in Siranzo cultivar with higher average fruit weight (Fig. 16 and Fig. 17). These results show the importance of correct cultivar selection in tomato cultivation in terms of nutrient balance and fruit quality. It was reported that the concentrations of macro (P, Na, K, Ca and Mg) and micro elements (Fe, Cu, Zn and Mn) in tomato fruits were affected by cultivar and cultivation method (Hernández Suárez et al., 2008, 2007). Negative

correlation was observed between plant nutrients and average fruit weight. Except for zinc and boron, other plant nutrients (N, K, Ca, P, Mg, S, Mn, Fe, Cu and Na) were positively correlated with each other. High positive correlation between N, K, Ca, P, Mg, S, Mn, Fe, Cu and Na and Zeatin, butyric acid, aspartate, aspargine, serine, tyrosine, phenylalanine, lysine, high negative correlation between abscisic acid, malic acid, maleic acid, threonine, proline. In general, when the cultivars are evaluated according to hormone content, the hormonal profile of the yellow-orange colored Operino cultivar stands out with its high ABA content despite its low IAA, GA and SA levels. In other yellow and orange cultivars, in general, except ABA hormone, other hormones in fruit tissues are lower than in red-colored cultivars. Especially red Idolini and Reddery cultivars were found to have balanced hormone contents (Table 6). According to the results of the correlation Fig. 17, negative correlation was detected between JA, GA, IAA, cytoconin, salicylic acid hormones and yellow color, while positive correlation was detected with ABA hormone. There was no correlation between fruit weight and hormones. In parallel with the conclusion that hormones have an effect on fruit color and fruit quality, it has been reported that ABA biosynthesis and signal transduction in blueberries are closely related to anthocyanin biosynthesis, anthocyanin accumulation and pericarp coloration. (Chung et al., 2019). Furthermore, fruit ripening, quality improvement and fruit morphology are regulated by ethylene, abscisic acid, auxin, jasmonic acid, brassinosteroid, salicylic acid, melatonin, transcription factors and environmental factors. The fruit ripening process is controlled by plant hormones alone or in combination. SA in particular has great potential to delay ripening, improve quality and control postharvest loss of both climacteric and non-climacteric fruits (Kou et al., 2021). Adjusting GA levels can alter tomato fruit morphology and regulate fruit ripening. Auxin is involved in the inhibition of fruit development and ripening (Iqbal et al., 2017). Hormones in tomatoes can indirectly increase the content of nutrients such as lycopene, vitamin C, flavonoids and phenolic compounds by influencing fruit development (Srivastava and Handa, 2005). Substances play an important role in the prevention of chronic diseases (Guil-Guerrero and Rebolloso-Fuentes, 2009). More studies are needed on the effects of hormones in tomato fruits on fruit quality and human metabolism. In particular, the therapeutic potential of hormones such as ABA and SA could be utilized in future diet-based health strategies. A high negative correlation between abscisic acid hormone and plant nutrients (N, K, Ca, P, Mg, S, Mn, Fe, Cu and Na) and a high positive correlation between zeatin and these nutrients were found.

The content of organic acids varies according to the color and size of tomato cultivars. Differences between these cultivars can affect the acidic properties, taste, nutritional value and processability of tomatoes. Each organic acid exists as a result of different biochemical processes in the fruit tissue and this plays a particularly prominent role in consumer preferences. Red cultivars, especially cultivars such as Idolini and Reddery, have high levels of oxalic, malonic and lactic acids in the fruit content, resulting in an acidic taste and a pronounced aromatic profile. The richer acidic nature of these cultivars can make the fruit more vibrant and pungent in flavor. Yellow and orange cultivars show less acidic characteristics compared to red cultivars. This leads to a softer and sweeter flavor. Maggino and Operino have particularly low levels of malonic acid and tartaric acid, resulting in a less acidic, sweeter flavor profile. The low acidic content can lead these cultivars to have a different nutritional profile. For example, lower acidic compounds may affect the bioavailability of some vitamins (especially vitamin C). However, the lower acidic characteristic may be more pleasant for some consumers, as these cultivars are less sour and sweeter. The Siranzo cultivar is generally less acidic, resulting in a sweeter and milder flavor, with significantly lower levels of succinic acid, oxalic acid, fumaric acid and butyric acid compared to the smaller cultivars. Larger cultivars generally have more balanced and mild flavors (Table 7). As they have lower acidic content, they may be ideal for those who prefer sweet and slightly acidic flavors. Also, because larger cultivars contain more water, they are usually juicier and sweeter. The accumulation of organic acids in plant cells is highly correlated with other metabolic pathways and appears to be under the control of many factors (Lin et al., 2016). Both the type and levels of organic acids are highly dependent on the species, developmental stages and tissue analyzed. Although variations in organic acid content are highly dependent on the fruit, it is in line with our results that citric acid is the most abundant organic acid in various fruits, and citric acid is an important compound for the fresh and tart flavor profile of the fruit (Batista-Silva et al., 2018). In our study, citric acid, lactic acid and fumaric acid were more prominent than other organic acids, which generally have a significant effect on the flavor profile and acidic content. In our study, red cultivars were generally higher in tartaric acid and malonic acid, with tartaric acid reported to cause a more pungent and sour taste. (Joye, 2019).

While glutamate, histidine, alanine, methionine, methionine, isoleucine, leucine and hydroxyproline amino acids were higher in red colored cultivars, asparagine, serine, tyrosine and phenylalanine amino acids were higher in yellow and almost yellow colored cultivars. The amino acid profile of tomato varies according to growing conditions, cultivar, fruit ripeness stages and fruit color (Baldina et al., 2016; Sorrequieta et al., 2010; Yu et al., 2022).

The reason for this was that organic acids and amino acids were low in the large-fruited cultivars and in general, there was a negative correlation between sucrose glucose and fructose and organic and amino acids. In addition, sucrose glucose and fructose sugars were positively correlated with each other. There was a negative correlation between sucrose and plant nutrients except zinc. There was a negative correlation between lycopene and yellow color, while there was a high positive correlation between plant nutrients, especially phosphorus. The high variability of sugar content in cultivated tomatoes is related to both genetic traits and growing conditions. The yellow, yellow orange and orange-colored tomato cultivars in our study had lower sugar levels than the red-colored tomatoes, which may be due to the fact that these cultivars are more closely related to wild tomato species. It has been shown that green fruits of wild tomato species accumulate mainly sucrose, while cultivated tomatoes accumulate glucose and fructose (Beckles et al., 2012). Differences in lycopene content between cultivars were found to be very large, including differences within fruit color groups. High lycopene content was found in cultivars with pink and orange-red fruit color, while much less accumulated in cultivars with green-yellow, yellow and yellow-purple fruit color (Kurina et al., 2021). Positive correlations were found between lycopene and indole acetic acid, roberellic and salicylic acid, butyric acid, alalnine lysine, glucose, fructose sucrose and total sugar. It was found that total phenolic content decreased as the fruit color moved away from red. As fruit weight increased, total flavonoids, vitamin C and antioxidant activity decreased in fruit tissues. High positive correlation was found between total flavonoids, vitamin C and antioxidant activity and other plant nutrients except zinc and boron. Total flavonoid, vitamin C and antioxidant activity were positively correlated with zeatin hormone and negatively correlated with malonic acid, malic acid, lactic acid, maleic acid, organic acids and amino acids glutamine, histidine, glycine, thereonine, methionine, cystine, hydroxyproline and proline. Total flavonoid, vitamin C and antioxidant activity compounds showed high positive correlation with each other (Fig. 17). In parallel with our results, a correlation between antioxidant activity and vitamin C between approximately 60 % and 100 % was reported. (Gardner et al., 2000). We found that flavonoid concentration was significantly affected by the cultivar of tomato plants. This finding is similar to the findings reported by Periago et al. (2002). These authors observed that flavonoid concentration was affected by tomato fruit cultivar and this variation could be due to genetic differences as well as different environmental stress conditions and agronomic practices affecting the chemical composition of plants.

The variation observed among pepper cultivars in terms of nutrient content and phytochemical composition is likely the result of a complex

interaction between genetic background and environmental conditions. The synthesis, transport, and accumulation of primary and secondary metabolites in plants are regulated by both inherent genetic traits and external stress factors (Ghasemzadeh and Ghasemzadeh, 2011; Kliebenstein, 2004). From a genetic perspective, each cultivar possesses a unique genetic architecture that determines the expression of key genes involved in primary and secondary metabolism. For instance, differences in total phenolic content and antioxidant capacity are often associated with the expression of genes encoding enzymes in the phenylpropanoid pathway, such as phenylalanine ammonia-lyase (PAL) and chalcone synthase (CHS) (Tohge et al., 2013; Ballester et al., 2010; Dixon and Paiva, 1995). Similarly, the biosynthesis of hormones like jasmonic acid and gibberellic acid is regulated by genes such as LOX, AOS, and GA20ox, and allelic variation in these genes may contribute to differences in hormone accumulation among cultivars (Wasternack and Hause, 2013).

Environmental factors also play a crucial role in shaping metabolic profiles. Conditions such as light intensity, temperature, water availability, and nutrient levels significantly influence the accumulation of various bioactive compounds (Hounsome et al., 2008). For example, higher light exposure can stimulate the production of flavonoids and anthocyanins, leading to deeper pigmentation (Jaakola, 2013), while stress conditions like drought or salinity may increase levels of proline, organic acids, and phenolic compounds as part of the plant's adaptive response (Khan et al., 2016; Nakabayashi et al., 2014).

5. Conclusion

This study revealed that the biochemical composition of tomato cultivars varies significantly depending on fruit color and size. Red cultivars (e.g., Idolini and Confetto) were the richest in vitamin C, flavonoids, lycopene, and antioxidant activity. Large-fruited cultivars (e.g., Siranzo) meet broader market demands with their sweeter, less acidic profiles, while small, brightly colored types are preferred in niche markets. Significant differences were observed among cultivars in terms of macro- and micronutrient content, organic acids, and amino acids. These findings underscore the importance of selecting the right cultivar to improve both agricultural productivity and nutritional quality. Red cultivars with high antioxidant content may be prioritized by health-conscious consumers, while yellow and orange cultivars with lower acidity are ideal for those seeking milder flavors. It offers valuable guidance for quality-oriented breeding programs and suggests that future research should focus on the health impacts of these compounds, particularly the role of phytochemicals in preventive health strategies.

Author contribution statement

The contributions of authors is defined as follows: study concept and design: H. B., A. A., H. A. and M. T.; data collection: A. A, H. B. and M. T.; analysis and interpretation of results: A. A., H. A. and H. B.; preparing a draft text: H. B., A. A. and H. A. Authors reviewed the results and approved the final version of the article.

CRediT authorship contribution statement

Metin Turan: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Data curation. **Hakan Başak:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Alim Aydin:** Writing – review & editing, Writing – original draft, Visualization, Resources, Methodology, Funding acquisition, Data curation, Conceptualization. **Hamide Aydin:** Writing – original draft, Resources, Investigation, Data curation.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jfca.2025.107992.

Data availability

Data will be made available on request.

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