

Article

From Sweet to Sour: Physicochemical Properties, Phenolic Compounds and Volatiles of Fresh Pomegranate Juices

Maja Veršić Bratinčević ^{1,*}, Ivana Generalić Mekinić ², Marijana Popović ¹ and Mira Radunić ^{3,4}

¹ Department of Applied Science, Institute for Adriatic Crops and Karst Reclamation, Put Duilova 11, 21000 Split, Croatia; marijana.popovic@krs.hr

² Department of Food Technology and Biotechnology, Faculty of Chemistry and Technology, University of Split, Ruđera Boškovića 35, 21000 Split, Croatia; ivana.generalic-mekinic@ktf-split.hr

³ Department of Plant Science, Institute for Adriatic Crops and Karst Reclamation, Put Duilova 11, 21000 Split, Croatia; mira.radunic@krs.hr

⁴ Centre of Excellence for Biodiversity and Molecular Plant Breeding, Svetošimunska cesta 25, 10000 Zagreb, Croatia

* Correspondence: maja.versic.bratincevic@krs.hr

Featured Application

Blending sweet and sour pomegranate juices from local Croatian cultivars offers a practical approach to producing natural, functional beverages with enhanced bioactive composition and improved sensory appeal.

Abstract

Pomegranate juice is a rich source of bioactive compounds, while its quality and organoleptic properties are influenced by the balance between sugars and organic acids. This study comparatively evaluated sweet, sour, and sweet–sour blended pomegranate juices by examining their physicochemical properties, color characteristics, phenolic content and volatile profile. Total phenolics, anthocyanins, and tannins were determined spectrophotometrically, and individual phenolics by HPLC-UV/VIS, while volatile compounds were identified using SPME-GC/MS. Significant differences ($p < 0.05$) were observed among juice types for all measured physicochemical and bioactive parameters. The sweet juice showed the highest total soluble solids to titratable acidity ratio (TSS/TA = 20.15) and the lowest tannin content (6.71 mg KE/L). The sour juice exhibited the highest acidity (2.28%) and tannin concentration (39.64 mg KE/L), along with lower L^* and a^* values. The sweet–sour juice presented a balanced TSS/TA ratio (10.50) and higher L^* , a^* , and b^* values. It also contained the highest levels of total phenolics (363.4 mg GAE/L, 10 and 12% higher than in sour and sweet juice, respectively) and anthocyanins (342.05 mg C3G/L, 25 and 65% higher than in sweet and sour juice, respectively). The volatile profile was dominated by (Z)-3-hexen-1-ol and 1-hexanol. Principal component analysis explained 91.9% of the total variance and clearly differentiated the samples according to acidity, sugar balance, and bioactive composition. These results highlight the potential of juice blending to enhance chemical composition and functional properties.

Keywords: pomegranate juices; physicochemical analysis; phenolic compounds; volatiles; color measurements; HPLC-UV/VIS; SPME-GC/MS



Academic Editor: Cláudia Neves

Received: 2 June 2026

Revised: 10 July 2026

Accepted: 16 July 2026

Published: 18 July 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

1. Introduction

Pomegranate (*Punica granatum* L.) is one of the oldest cultivated fruit species, traditionally grown throughout the Mediterranean region, especially in southern Europe, western

Asia and northern Africa, while today it is also widespread in other parts of Asia and the Americas [1–3]. In recent decades, pomegranate cultivation has expanded to subtropical and tropical regions, driven by increasing knowledge of its nutritional and functional value. It is a highly valued fruit species recognized for its unique sensory attributes and exceptional nutritional profile, which is rich in bioactive compounds like phenolic acids, flavonoids, tannins, and anthocyanins [4], which are associated with antioxidant activity and potential health benefits such as reduced risk of cardiovascular diseases, cancer, and metabolic disorders [5,6]. Therefore, precise characterization of these compounds is essential for understanding their biological activity and evaluating the functional potential of pomegranate juice. Among these compounds, anthocyanins—primarily derivatives of delphinidin, cyanidin, and pelargonidin—play a key role in both antioxidant capacity and fruit coloration [7,8]. The chemical composition and quality of pomegranate fruit and juice are influenced by multiple factors, including genotype, environmental conditions, fruit maturity stage, and processing methods [3,9,10]. Radunić et al. [8] conducted a study on pomegranate accessions from Croatia and they demonstrated significant variability in physical and chemical properties among local cultivars, with differences recorded in fruit weight, phenolic content, and anthocyanin composition, confirming the strong influence of genotype on fruit quality. Variations in phenolic content, sugar composition, and antioxidant activity have been widely reported across cultivars, growing regions, and extraction approaches [11–13]. In particular, the balance between sugars and organic acids is a key determinant of sensory quality, while anthocyanin content and composition contribute significantly to color characteristics and consumer acceptance [10,14]. In addition to phenolic composition, volatile compounds are an important factor in the sensory quality of pomegranate juice, although their relationship with flavor characteristics has not yet been sufficiently investigated [15].

Pomegranate is consumed both as fresh fruit and in processed forms, with juice representing one of the most important products due to its sensory properties and high content of health-promoting compounds [16,17]. Precise chemical characterization of these compounds requires advanced analytical approaches such as liquid and gas chromatography, which allow for detailed profiling of phenolic acids, anthocyanins, and volatile compounds. Blending juices with different flavor profiles represents a promising approach to optimize the sensory and functional properties of pomegranate juice [18].

Most available studies have focused on widely grown cultivars, such as Wonderful or Mollar, while the physicochemical, phenolic and volatile profiles of locally grown cultivars are still largely unexplored. Although cultivar-dependent variability in the physicochemical and bioactive properties of Croatian pomegranate has been documented [8,19], the potential of combining cultivars with contrasting flavor profiles to modulate juice quality and organoleptic characteristics has not been explored. To our knowledge, a direct comparison of sweet, sour, and sweet–sour juices from Croatian cultivars within a single analytical framework has not been previously reported, and the practical potential of blending locally grown cultivars with contrasting flavor profiles to enhance juice quality remains unexplored.

The aim of this study was to comparatively evaluate sweet, sour, and sweet–sour blended pomegranate juices from local cultivars by analyzing their physicochemical characteristics, phenolic composition, color parameters, and volatile profiles, using combined spectrophotometric, high performance liquid chromatography (HPLC), and gas chromatography/mass spectrometry (GC/MS) analyses.

2. Materials and Methods

2.1. Fruit Samples and Juice Preparation

This study was conducted on fruit samples from native pomegranate cultivars traditionally grown along the eastern Adriatic coast. Sweet juice was prepared from cultivars 'Barski slatki', 'Sladun', and 'Slatki tankokorač', sour juice from cultivars 'Pastun' and 'Zamorac', and sweet-sour juice was obtained by blending all five cultivars. The cultivars are maintained in the Gene Bank of Mediterranean Fruit Species at the Institute for Adriatic Crops and Karst Reclamation, Split, Croatia (43°30'22" N; 16°29'47" E; 60 m a.s.l.). The trees were bush-shaped with three to four main trunks, planted at a spacing of 4.5 m × 3 m, drip-irrigated, and managed according to standard horticultural practices including pruning, fertilization, and plant protection.

Fruit samples were collected randomly around the canopy of each cultivar at commercial maturity and assessed for fruit size and external color between 15 and 30 October. Thirty fruits per type of juice were transported to the laboratory, washed in distilled water, dried, cut in half and immediately pressed with a mechanical press (Maskot M-ST, Mutfak Eşyaları Ltd. Şti., Kahramanmaraş, Turkey). Since juice yield varies by cultivar, individual cultivar juices within each group were combined in equal volumes rather than weighted by fruit or juice yield, ensuring equal cultivar representation in the final composite. For each juice type (sweet, sour, and sweet-sour), a composite batch of approximately 200 mL was prepared. Pomegranate juices were immediately stored at 4 °C until analysis, and filtered through PTFE syringe filters (0.22 µm) prior to analysis. All analyses were performed in analytical triplicate ($n = 3$), except for volatile compounds ($n = 2$).

2.2. Chemicals and Reagents

Folin–Ciocalteu reagent, gallic acid, sodium carbonate, sodium hydroxide, phenolphthalein, gelatin, polyvinyl polypyrrolidone (PVPP) and distilled water were used for spectrophotometric analyses. Standard solutions of gallic acid, neochlorogenic acid, chlorogenic acid, caffeic acid, *o*-coumaric acid, cinnamic acid, and cyanidin-3-glucoside were purchased from Sigma-Aldrich (St. Louis, MO, USA) and prepared in 80% HPLC-grade methanol (VWR International, Radnor, PA, USA). HPLC-grade acetonitrile and 85% *o*-phosphoric acid (both Sigma-Aldrich) were used as mobile phase components. Prior to HPLC analysis, samples were filtered through 0.22 µm PTFE syringe filters and injected into the system (10 µL).

2.3. Determination of Physicochemical Properties

Total soluble solids (TSS) were measured using a digital refractometer (My Brix, Mettler Toledo, Greifensee, Switzerland) and expressed as °Brix. Titratable acidity (TA) was determined by titration with NaOH and expressed as percentage of citric acid. The TSS/TA ratio was calculated to evaluate the sugar–acid balance of the juices.

2.4. Determination of Phenolic Compounds

Total phenolic content (TP) was determined using the Folin–Ciocalteu method. [20] The absorbance was measured at 765 nm after the reaction mixture had been incubated for 2 h at room temperature in the dark. TP content was calculated from the gallic acid calibration curve ($y = 0.001x + 0.0061$, $R^2 = 0.9997$) and the results were expressed as mg of gallic acid equivalents (GAE) per liter.

Total anthocyanins (TAnts) were determined using the pH differential method, calculated using the data for the predominant anthocyanin (cyanidin-3-glucoside, C3G) and expressed as mg of C3G equivalents per liter.

Total tannin (TT) content was determined by the vanillin–HCl method [20]. The absorbance of the reaction mixture was measured at 510 nm after incubation for 20 min at room temperature. TTs were quantified using a catechin calibration curve ($y = 0.0009x + 0.0118$, $R^2 = 0.9983$) taking into account the sample dilution factor (1:10), and the results are expressed as mg of catechin equivalents (KEs) per liter.

HPLC analysis of individual phenolic acids and anthocyanins was performed using a Shimadzu Nexera LC-40 HPLC system (Shimadzu, Kyoto, Japan) equipped with a UV-Vis detector, according to Kamal et al. [21], with slight modification depending on whether phenolic acids or anthocyanins were determined. Separation was carried out using a reversed-phase Phenomenex C18 column (250 mm $\times$ 4.6 mm, particle size 5 μ m; Phenomenex, Torrance, CA, USA).

Anthocyanins: For the preparation of the calibration curve, seven concentration levels of cyanidin-3-glucoside standard solution were injected in triplicate into the HPLC system using an autosampler. The calibration curve was used for the approximation and quantification of anthocyanins in pomegranate samples. The analysis was performed at a flow rate of 1 mL/min and a column temperature of 30 °C. Mobile phase A consisted of ultrapure water and 85% *o*-phosphoric acid (Sigma-Aldrich) in a ratio of 99.8:0.2 (*v/v*), while mobile phase B was HPLC-grade acetonitrile (VWR International, Radnor, PA, USA). Anthocyanins were monitored at 480 and 520 nm, with 520 nm selected for identification. The total run time was 25 min using the following gradient program: initial 96% A, 7.5 min 90% A, 20 min 80% A, 21 min 96% A, followed by 4 min re-equilibration.

Phenolic acids: For the preparation of the calibration curve, seven concentration levels of standard solutions were injected in triplicate into the HPLC system using an autosampler. The analysis was performed at a flow rate of 1 mL/min and a column temperature of 30 °C. Mobile phase A consisted of ultrapure water and 85% *o*-phosphoric acid (Sigma-Aldrich) in a ratio of 99.8:0.2 (*v/v*), while mobile phase B consisted of HPLC-grade acetonitrile (VWR International, Radnor, PA, USA). Phenolic acids were monitored at wavelengths of 220 and 320 nm; gallic, *o*-coumaric, and cinnamic acids were detected at 220 nm, and neochlorogenic, chlorogenic, and caffeic acids were detected at 320 nm. The total run time was 40 min using the following gradient program: initial 96% A, 7.5 min 91% A, 9 min 85% A, 18 min 79% A, 33 min 60% A, 34 min 96% A, followed by 6 min re-equilibration.

2.5. Color Characteristics of Pomegranate Juice

Color parameters of pomegranate juice samples were measured using a Chroma Meter CR-400 (Konica Minolta, Osaka, Japan) and expressed in the CIELAB color space. The following parameters were recorded: L^* (lightness, ranging from 0 to 100), a^* (red–green axis, with positive values indicating redness and negative values indicating greenness), b^* (yellow–blue axis, with positive values indicating yellowness and negative values indicating blueness), chroma (C^* , representing color intensity), and hue angle (h° , representing the visual color appearance, where values of 0–90° correspond to red–violet, 90–180° to yellow, 180–270° to blue–green, and 270–360° to blue) [22]. All measurements were carried out in triplicate.

2.6. Analysis of Volatile Compounds

Isolation of volatile organic compounds (VOCs) from pomegranate juice was performed by solid-phase microextraction (SPME) with 50/30 μ m DVB/CAR/PDMS fiber purchased from Supelco (Sigma-Aldrich, Bellefonte, PA, USA) according to Vázquez-Araújo [23], with a slight modification. The fiber was conditioned at 250 °C for 1 h before use. For sample preparation, 2 mL of pomegranate juice and 0.5 g NaCl were placed in 20 mL glass vials, which were sealed with magnetic caps with silicone septa. The SPME

fiber was inserted into the vial headspace, and the samples were equilibrated at 40 °C for 30 min, followed by fiber transfer to the GC injection port for thermal desorption, which was conducted at 250 °C for 3 min. Analysis was performed in duplicate. Volatile compounds were reported as relative abundances obtained by HS-SPME-GC-MS, and used for comparative profiling of aroma composition among samples.

2.7. Statistical Analysis

Statistical analyses were performed in R statistical software (v4.4.0; R Core Team, 2024). Data are presented as means $\pm$ standard deviations ($n = 3$), except for volatile compounds ($n = 2$). Differences between groups were assessed by one-way ANOVA followed by Tukey's post hoc test, with significance accepted at $p \leq 0.05$. Principal component analysis (PCA) was used to assess the overall relationship among all juice samples based on total soluble solids (TSS), titrable acidity (TA), total phenolics (TPs), total anthocyanins (TAnts), total tannins (TTs), and color parameters. A Pearson correlation heatmap was generated using standardized data to examine relationships between total and individual phenolic acids and anthocyanins.

3. Results and Discussion

The physicochemical properties, phenolics, color characteristics and volatile profile of sweet, sour and sweet-sour fresh pomegranate juice were evaluated to determine differences between samples and compare their profiles, particularly in terms of chemical composition, color and aromatic profile. The results are presented and discussed according to the main groups of analyzed parameters, with an emphasis on differences between juice types and their relationship to functional and sensory properties.

3.1. Physicochemical Properties of Pomegranate Juices

All evaluated physicochemical parameters differed significantly ($p < 0.05$) among the analyzed fresh pomegranate juices (Table 1). TSS ranged from 17.57 to 18.63 °Brix; the sour juice showed the highest TSS content, while the lowest was reported in the sweet juice. This relatively small range of TSS values agrees with the results of Mphahlele et al. [3], who reported that soluble solids content in pomegranate juice depend more on cultivar and maturity than on processing conditions. Furthermore, similar TSS values were reported by Tarantino et al. [24] with values ranging from 14.7 to 17.8 °Brix among different pomegranate cultivars, suggesting that the analyzed juices in our study fall within the expected ranges for both fresh and commercial juices. On the other hand, TA varied substantially, ranging from 0.87% in sweet juice to 2.28% in sour juice, while the sweet-sour juice showed an intermediate value of 1.71%. Variability in TA has been widely reported in the literature and is mainly associated with cultivar, fruit maturity, environmental conditions, and genotype [25,26]. Tarantino et al. [24] also reported a comparable acidity range (0.6–2.3% citric acid), where sour cultivars like 'Wonderful' and 'Wonderful Super' had the highest acidity, similar to the results of sour juice analyzed in this study. In this study, the TSS/TA ratio clearly separated the juice samples according to their sensory profile. The highest TSS/TA ratio was found in the sweet juice (20.15), followed by the sweet-sour juice (10.50), while the sour juice had the lowest value (8.16). According to the previous studies, the TSS/TA ratio represents one of the most important indicators of maturity and sensory quality, as it directly shapes sweetness perception and consumer acceptance [27,28]. This aligns with Tarantino et al. [24], who classified cultivars with higher TSS/TA values as sweet or sweet-sour, and those with lower ratios as sour. Based on these criteria, the sweet juice from our study appears more suitable for fresh consumption, whereas the sour juice reflects cultivars defined by higher acidity and a sharp, sour taste.

Table 1. Physicochemical characteristics of sweet, sour and sweet–sour pomegranate juices (mean $\pm$ SD).

Sample	TSS ($^{\circ}$ Brix)	TA (%)	TSS/TA
Sweet juice	17.57 $\pm$ 0.40 ^b	0.87 $\pm$ 0.04 ^c	20.15 $\pm$ 1.09 ^a
Sour juice	18.63 $\pm$ 0.12 ^a	2.28 $\pm$ 0.02 ^a	8.16 $\pm$ 0.03 ^c
Sweet–sour juice	17.87 $\pm$ 0.15 ^b	1.71 $\pm$ 0.11 ^b	10.50 $\pm$ 0.74 ^b

Values are expressed as the means $\pm$ standard deviations ($n = 3$). TSS—total soluble solids; TA—titrable acidity. Different letters within the same column indicate significant differences according to Tukey's HSD test at $p < 0.05$.

3.2. Phenolic Compounds

TPs and TAnts differed significantly among the samples ($p < 0.05$) (Table 2). The sweet–sour juice contained the highest levels for both TPs (363.37 mg GAE/L) and TAnts (342.05 mg C3G/L). The sweet juice contained intermediate levels of anthocyanins but lower total phenolics compared to the sweet–sour sample. The results obtained indicate a possible relationship between the flavor profile of cultivars and their bioactive composition. This phytochemical profile aligns with the results of Gómez-Caravaca et al. [7] and Akhavan et al. [29], who documented wide, cultivar-dependent variations in the phenolic composition of pomegranate juices. In contrast, the sour juice had the lowest TAnts (117.56 mg C3G/L), despite its high acidity and TT content (39.64 mg KE/L). This reflects the cultivar-dependent nature of anthocyanin accumulation reported in the literature by Mottaghipisheh et al. [30] and Gil et al. [11]. In the sweet juice, the anthocyanin levels were intermediate (257.72 mg C3G/L), but the TP content was lower (319.97 mg GAE/L) than in the sweet–sour sample. These results indicate that cultivar-specific metabolic pathways likely play a stronger role in determining phenolic distribution than the sugar–acid ratio alone. The lower anthocyanin content in the sour juice most likely reflects genotype-specific differences in anthocyanin biosynthesis, with environmental conditions such as the Adriatic microclimate potentially contributing secondarily. Nevertheless, the balance between sugars and acids may still influence compound stability during fruit development and extraction [11,24]. From a commercial and nutritional perspective, the rich bioactive profile of the investigated sweet–sour juice highlights its potential as a valuable base for functional beverages with high antioxidant activity and desirable visual appeal.

Table 2. Total phenolics, anthocyanins and tannins in analyzed pomegranate juices (mean $\pm$ SD).

Sample	Total Phenolics (mg GAE/L)	Total Anthocyanins (mg C3G/L)	Total Tannins (mg KE/L)
Sweet juice	319.97 $\pm$ 3.1 ^c	257.72 $\pm$ 1.5 ^b	6.71 $\pm$ 1.96 ^b
Sour juice	329.48 $\pm$ 1.0 ^b	117.6 $\pm$ 2.9 ^c	39.64 $\pm$ 1.21 ^a
Sweet–sour juice	363.37 $\pm$ 0.1 ^a	342.05 $\pm$ 2.5 ^a	7.48 $\pm$ 2.77 ^b

Values are expressed as the means $\pm$ standard deviations ($n = 3$). Different letters within the same column indicate statistically significant differences according to Tukey's HSD test at $p < 0.05$. GAE—gallic acid equivalents; C3G—cyanidin-3-glucosides.

TTs differed significantly among the three fresh pomegranate juices, following a similar trend observed for TA. The sour juice showed the highest TT value (39.64 mg KE/L), while the sweet and sweet–sour juices showed lower and statistically similar concentrations (6.71 and 7.48 mg KE/L, respectively), indicating a cultivar-related difference in the accumulation of these polyphenols. A similar variation was reported by Mottaghipisheh et al. [30], who reported significant variation in TT content among seven pomegranate cultivars grown in Iran. Since pomegranate tannins consist mostly of ellagitannins and other hydrolyzable tannins, the higher TT value in sour juice likely reflects a higher proportion of these compounds compared to the sweet and sweet–sour samples [7]. Because these components contribute directly to bitterness and astringency, their high concentration is bound to shape

the overall sensory profile of the juice. Altogether, these results suggest that TT content represents a cultivar-dependent characteristic with a strong influence on pomegranate juice quality [30].

The individual anthocyanin and phenolic acid profiles of the sweet, sour, and sweet–sour pomegranate juices, determined using HPLC, are presented in Table 3.

Table 3. High performance liquid chromatography analysis of anthocyanins and phenolic acids.

	Sweet Juice	Sour Juice	Sweet–Sour Juice
	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD
Anthocyanins (mg/L)			
Cyanidin 3,5-diglucoside	29.67 $\pm$ 0.11 ^b	9.35 $\pm$ 0.13 ^c	44.75 $\pm$ 0.36 ^a
Delphinidin 3,5-diglucoside	25.98 $\pm$ 0.05 ^b	8.90 $\pm$ 0.06 ^c	42.91 $\pm$ 0.56 ^a
Pelargonidin 3,5-diglucoside	20.35 $\pm$ 0.10 ^b	14.33 $\pm$ 0.01 ^c	30.41 $\pm$ 0.34 ^a
Cyanidin 3-glucoside	30.73 $\pm$ 0.58 ^b	20.59 $\pm$ 0.01 ^c	35.91 $\pm$ 0.45 ^a
Pelargonidin 3-glucoside	2.40 $\pm$ 0.03 ^a	1.64 $\pm$ 0.03 ^c	2.24 $\pm$ 0.20 ^b
Phenolic acids (mg/L)			
Gallic acid	11.55 $\pm$ 0.10 ^a	9.73 $\pm$ 0.05 ^b	11.41 $\pm$ 0.26 ^a
Neochlorogenic acid	5.15 $\pm$ 0.12 ^b	4.94 $\pm$ 0.07 ^b	6.49 $\pm$ 0.13 ^a
Chlorogenic acid	6.51 $\pm$ 0.24 ^a	6.46 $\pm$ 0.29 ^a	6.54 $\pm$ 0.17 ^a
Caffeic acid	11.75 $\pm$ 0.10 ^a	7.22 $\pm$ 0.38 ^b	7.35 $\pm$ 0.43 ^b
<i>o</i> -Coumaric acid	1.13 $\pm$ 0.06 ^b	1.50 $\pm$ 0.10 ^a	0.80 $\pm$ 0.04 ^c
Cinnamic acid	0.19 $\pm$ 0.01 ^a	tr.	tr.

Values are expressed as mean $\pm$ standard deviation (SD). Different letters within the same column indicate significant differences between samples according to Tukey HSD test ($p \leq 0.05$); tr. = trace amounts.

HPLC analysis showed that cyanidin 3-glucoside and cyanidin 3,5-diglucoside were the dominant anthocyanins in all tested samples (Table 3). The sweet–sour juice had the highest concentrations of almost all identified anthocyanins, which explains its rich pigment profile. The lowest concentrations were measured in the sour juice sample, while the sweet juice consistently showed intermediate values. The higher anthocyanin content in the sweet–sour juice is probably a result of combined cultivars with different anthocyanin profiles. Since these pigments are directly responsible for the characteristic red color of pomegranate juice, higher concentrations in the sweet–sour sample are expected to enhance color intensity. The predominance of cyanidin derivatives across all samples confirms the anthocyanin profile characteristic of pomegranate juice [31,32]. According to Mena et al. [27], anthocyanins are the main pigments responsible for the red, purple and blue colors of plant tissues. Their stability depends on various factors such as pH, oxygen, temperature, light and storage conditions, with heat treatment representing one of the most significant degradation factors. Fischer et al. [14] confirmed this, reporting a significant reduction in anthocyanin content in pomegranate juice subjected to temperatures between 60 °C and 90 °C. Since no heat treatment was applied, the anthocyanin profile of the analyzed fresh juices was probably well preserved. The dominance of cyanidin derivatives in all analyzed samples confirms their key role in determining the characteristic color of pomegranate juice, while the differences observed between sweet, sour, and sweet–sour samples further point to the influence of cultivar on anthocyanin composition and concentration [27].

HPLC analysis of phenolic acids in fresh pomegranate juice (Table 3) showed that gallic and caffeic acids were the dominant compounds in all tested samples, while chlorogenic and neochlorogenic acids were present in slightly lower concentrations. *o*-coumaric and cinnamic acids were quantified in significantly lower concentrations, and cinnamic acid was not quantified, but was present only in traces, which is probably a consequence of

its conversion into other phenolic derivatives during biosynthesis [33]. The sweet–sour blend showed the highest concentrations of individual phenolic acids, following the trend observed for total phenolic content (Table 2), with the sour juice consistently showing the lowest values across individual compounds. The identified and quantified compounds belong primarily to the hydroxybenzoic and hydroxycinnamic acid groups, so our results further support their significant contribution to the overall phenolic profile and antioxidant properties of pomegranate juice [34]. The concentration differences among the samples, particularly for caffeic acid, are strongly connected to cultivar traits, fruit maturity, and agro-climatic conditions [35]. Among the identified compounds, caffeic acid showed significantly higher concentrations in sweet juice (11.75 mg/L) compared to sour and sweet–sour samples, indicating cultivar-specific differences in hydroxycinnamic acid accumulation. Karakaplan and Özcan [36] similarly identified caffeic acid as the dominant phenolic acid in freshly squeezed, commercial, and concentrated pomegranate juices from Turkey, quantifying a total of five phenolic acids—gallic, chlorogenic, caffeic, *p*-coumaric, and ferulic acids—with caffeic acid concentrations ranging from 61 to 422.8 mg/L depending on the juice type. Although gallic and caffeic acids predominated in all tested samples and represent the main contributors of the bioactive potential of pomegranate juice, the total antioxidant capacity still represents the combined action of multiple phenolic compounds, including flavonoids and tannins.

The observed differences in pomegranate juice composition result not only from compounds naturally present in the used cultivars, but also from their interactions within the juice blends. The sweet–sour juice was prepared by blending juices from all five cultivars in equal proportions (20% each), not by mixing sweet and sour juices in a 1:1 ratio; therefore, its composition cannot be considered a simple arithmetic average of the sweet and sour juice compositions. This is particularly relevant for phenolic composition, as the cultivars from the sweet juice group made up 60% of the blend, which likely contributed to the higher concentrations of individual anthocyanins in the sweet–sour sample. Since anthocyanin forms are strongly pH-dependent, the high TA of the sweet–sour juice (Table 2) may also explain the observed differences in their profile and content.

Another important factor is the oxidative degradation of anthocyanins, which is strongly influenced by the number of hydroxyl groups on the B-ring. Accordingly, delphinidin and cyanidin derivatives are therefore less stable than pelargonidin derivatives, which have only one hydroxyl group. The increase in delphinidin and cyanidin derivatives compared to pelargonidin derivatives further supports this interpretation. Finally, synergistic effects between cultivar-specific metabolites, organic acids (higher TA value of the sweet–sour juice) and phenolic compounds, through antioxidant effects and copigmentation phenomena [37–39], may have further influenced the presence and stability of the investigated compounds.

3.3. Pomegranate Juice Color Characteristics

The CIELAB color parameters differed significantly among the three fresh pomegranate juices (Figure 1). The sweet juice showed the highest a^* value, indicating a more intense red color, while the sour juice exhibited the highest b^* value, reflecting a stronger yellow component. Sweet–sour juice showed intermediate values for a^* and b^* , a pigment composition that combines characteristics of both juice types. These variations are likely due to differences in pigment composition, especially the distribution and abundance of individual anthocyanins [24]. The increased b^* value in sour juice, despite the lower total anthocyanin content, probably reflects differences in anthocyanin composition, not just concentration. The relatively higher proportion of pelargonidin derivatives, which absorb at longer wavelengths and contribute to orange–red hues [6], may explain the more

pronounced yellow component observed in this sample. Similarly, the relatively small differences in a^* values among juice types suggest that red color intensity is determined not solely by total anthocyanin concentration, but also by the specific composition of anthocyanin derivatives present in each juice type. The L^* values obtained in our study (21.42–22.00) are comparable to those reported by Tarantino et al. [23] for fresh pomegranate juices from Italian cultivars (20.3–25.6), confirming similar lightness characteristics across geographically distinct cultivars. The a^* values of our samples (6.50–7.72) fell toward the lower end of their reported range (4.1–13.0), while b^* values (2.72–4.24) were somewhat higher than most of their cultivars, pointing to a slightly more pronounced yellow component in the Croatian cultivars in our study. A similarly wide range of color parameters was reported by Peng et al. [40], who analyzed six pomegranate varieties from Yunnan, China, and determined L^* values from 12.74 to 49.22 and a^* values from 6.20 to 33.75. The values obtained in the present study fall within this broad range, further underlining how strongly pomegranate juice color depends on cultivar and growing conditions.

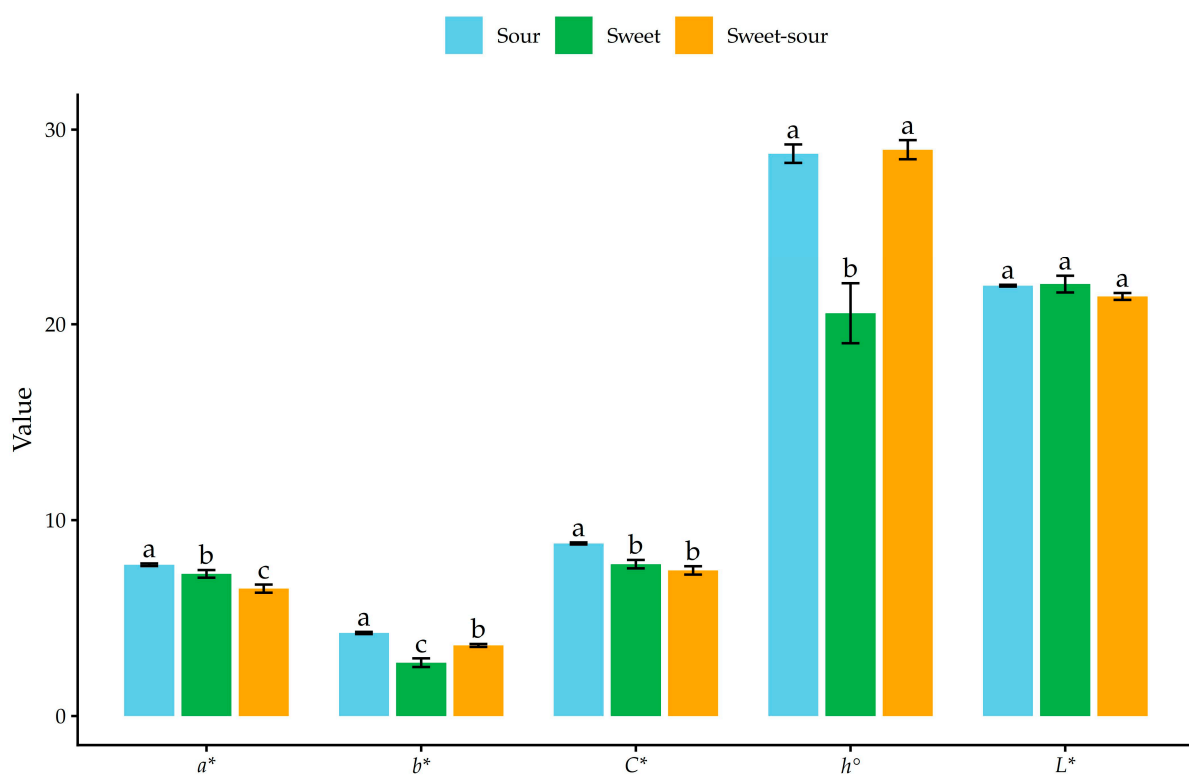


Figure 1. CIELab color parameters of sweet, sour and sweet–sour pomegranate juices. Error bars represent standard deviation. Different letters above bars indicate significant differences according to Tukey’s HSD test at $p < 0.05$.

3.4. Volatile Compounds

Qualitative analysis of volatile compounds using SPME/GC-MS showed significant differences in the composition and relative proportions of aromatic compounds among the tested samples (Table 4). The aromatic profile of all samples was dominated by the group of C6 compounds, with 1-hexanol being the most abundant component with relative proportions ranging from 43.56% in sour to as much as 58.81% in sweet juice. In addition, high proportions were also recorded for (Z)-3-hexen-1-ol (19.28–25.66%), with slightly lower values of hexanal. These compounds contribute to green and fresh aromatic notes [23,32]. In addition to the C6 alcohol profile, the presence of aldehydes, monoterpenes and esters was confirmed in all juices, the proportions of which differed depending on the juice mixture, i.e., sweet, sour or sweet–sour cultivars. While benzaldehyde and limonene contributed to

a fruitier aromatic impression, sour and sweet-sour samples exhibited a more pronounced terpene profile, primarily due to the higher content of α -terpineol (about 13%) and sabinene derivatives. Also, a very high content of methyl salicylate (11.95%) was recorded in the sour juice, which in the other two samples varied in significantly lower amounts (1.22% and 2.38%), indicating a specific contribution of this ester to the sharper aromatic profile of the sour cultivar. On the other hand, toluene was determined only in minimal amounts (about 1%) in the sour and mixed juice, while its presence was not determined in the sweet sample. These results are in accordance with the statements of Vázquez-Araújo et al. [24], who also determined the dominant role of these groups of compounds in shaping the aroma of pomegranate in commercial and fresh juices of the Wonderful cultivar. According to the literature data, the composition of volatile compounds significantly depends on the cultivar, growing area, maturity level and processing conditions [41,42]. Although terpene compounds are often present in smaller quantities, due to the low threshold of sensory perception they also contribute to the recognizable aroma of pomegranate. In contrast to research conducted on commercial and thermally processed juices [23,43], the presence of furan compounds such as 2-furfural and 5-methyl-2-furfural, which are most often formed during thermal processing as products of Maillard reactions and carbohydrate degradation [32], was not demonstrated in the analyzed samples. Their absence in this work directly confirms that the absence of thermal processing successfully preserved the original, natural volatile profile of fresh pomegranate fruit.

Table 4. Volatile compounds identified in pomegranate juices (% relative abundance).

Compound	RI	Sweet		Sour		Sweet-Sour	
		Mean	$\pm$ SD	Mean	$\pm$ SD	Mean	$\pm$ SD
Toluene	<800	/	/	1.06	0.11	0.96	0.45
Hexanal	<800	1.02	0.05	0.81	0.08	1.36	0.26
(Z)-3-Hexen-1-ol	843	22.21	1.95	19.28	1.82	25.66	0.42
1-Hexanol	858	58.81	4.55	43.56	3.31	47.56	1.99
Benzaldehyde	940	2.95	0.71	1.09	0.07	2.10	0.73
Limonene	994	1.35	0.57	0.98	0.65	1.00	0.18
2-Nonanone	1050	1.87	0.66	1.55	0.18	0.75	0.23
(Z)-Sabinene hydrate	1052	1.54	0.03	1.48	0.07	1.16	0.08
Nonanal	1060	1.31	0.58	1.77	0.32	0.93	0.08
(E)-Sabinene hydrate	1107	1.01	0.00	2.57	0.27	2.72	0.2
α -Terpineol	1120	6.74	0.29	13.92	3.01	13.47	0.35
Methyl salicylate	1123	1.22	0.35	11.95	1.24	2.38	0.02

Values are presented as relative abundance (%) and expressed as mean $\pm$ SD, and the results are interpreted as differences in volatile composition and relative aroma contribution.

3.5. Multivariate and Correlation Analysis

PCA and a correlation heatmap were applied to examine the relationships among the selected measured parameters and visualize the separation between the juice types, with PCA based on TSS, TA, TPs, TAnts, TTs and color parameters, as these variables describe the main physicochemical, bioactive and visual differences between the samples. A correlation heatmap was used to investigate whether individual phenolic compounds and anthocyanins follow similar distribution patterns in the three juice types. The first two principal components explained 91.9% of the total variance (Dim1 = 53.9%, Dim2 = 38.0%), confirming that the biplot provides a reliable representation of the data set (Figure 2).

All three juice types occupied different positions in the biplot. The sour juice was clustered on the far right along Dim1, associated with the vectors TA, b^* and TSS, which is consistent with its high acidity and tannin content (Table 1). The sweet-sour juice

was clustered in the upper left corner, along the vectors TP and TAnt, consistent with its highest phenolic and anthocyanin content (Tables 2 and 3). The sweet juice separated primarily along Dim2, in the direction of the L^* vector, pointing to lightness as its primary distinguishing characteristic among the three juice types (Figure 1). The vectors TA and b^* were oriented in a similar direction, indicating a positive association between acidity and the yellow color component. By contrast, the TAnt and TP vectors are oriented in the opposite direction along Dim1, which is consistent with the inverse relationship between acidity and phenolic composition described earlier (Sections 3.2 and 3.3).

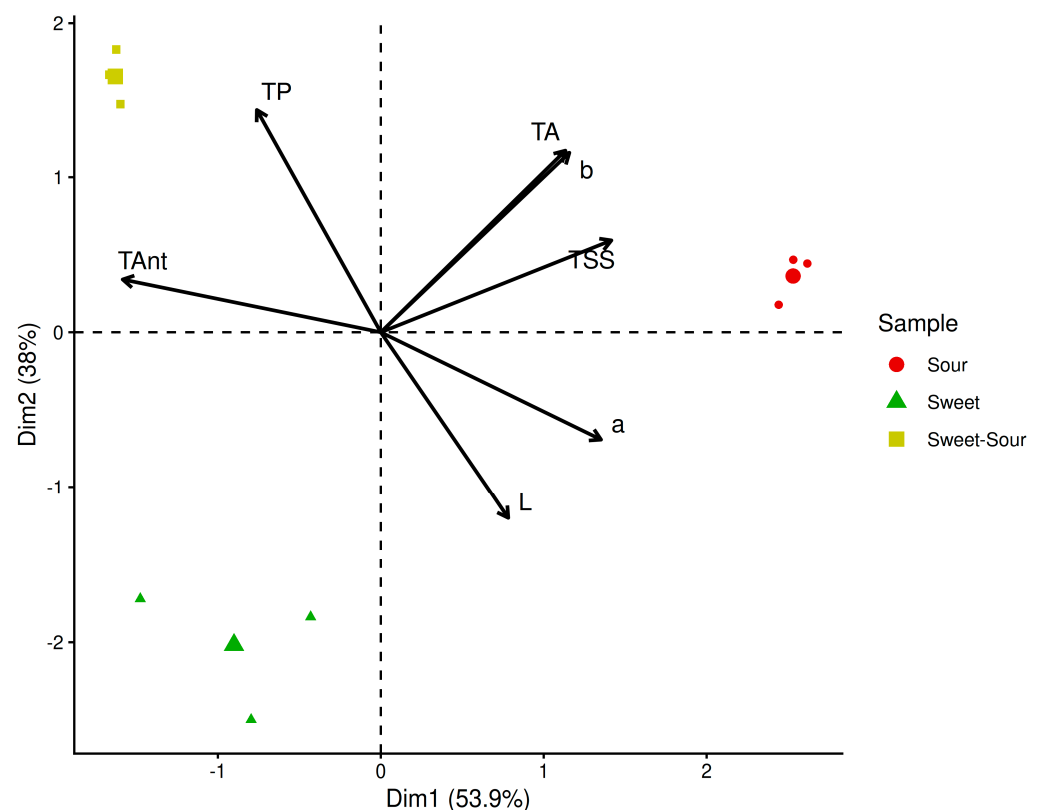


Figure 2. Principal component analysis (PCA) biplot of physicochemical and bioactive parameters of sweet, sour, and sweet-sour pomegranate juices.

The correlation heatmap showed two clear clusters (Figure 3). The first cluster included TAnts and anthocyanin diglucoside derivatives, which were strongly positively correlated, confirming their dominant contribution to the TAnt content [7,27]. The second cluster consisted of TPs, individual phenolic acids and anthocyanins, also with strong mutual correlations, indicating a similar pattern of distribution of these compounds in all analyzed juices. A pronounced negative correlation was observed between the two clusters—juices with a higher content of diglucoside anthocyanins had lower concentrations of phenolic acids and vice versa. This pattern probably reflects varietal differences in the distribution of phenylpropanoid precursors towards different biosynthetic pathways, which has been previously observed for pomegranate juices from Iranian and Chinese cultivars [13,30].

Together, PCA and heatmap analysis showed that juice type was primarily determined by cultivar-specific differences in phenolic composition, supporting the use of blending to modulate the quality and functional balance of pomegranate juice.

Finally, the main objective of this study was to compare the phytochemical profiles of the investigated pomegranate juices with respect to their nutritional and functional characteristics. The samples were compared using measurable parameters—sugars and organic acids as the main flavor carriers, and tannin content, which is usually associated

with the perception of astringency and bitterness. The presence and concentration of color compounds and volatiles were also taken into account to partially explain the sensory characteristics of the samples.

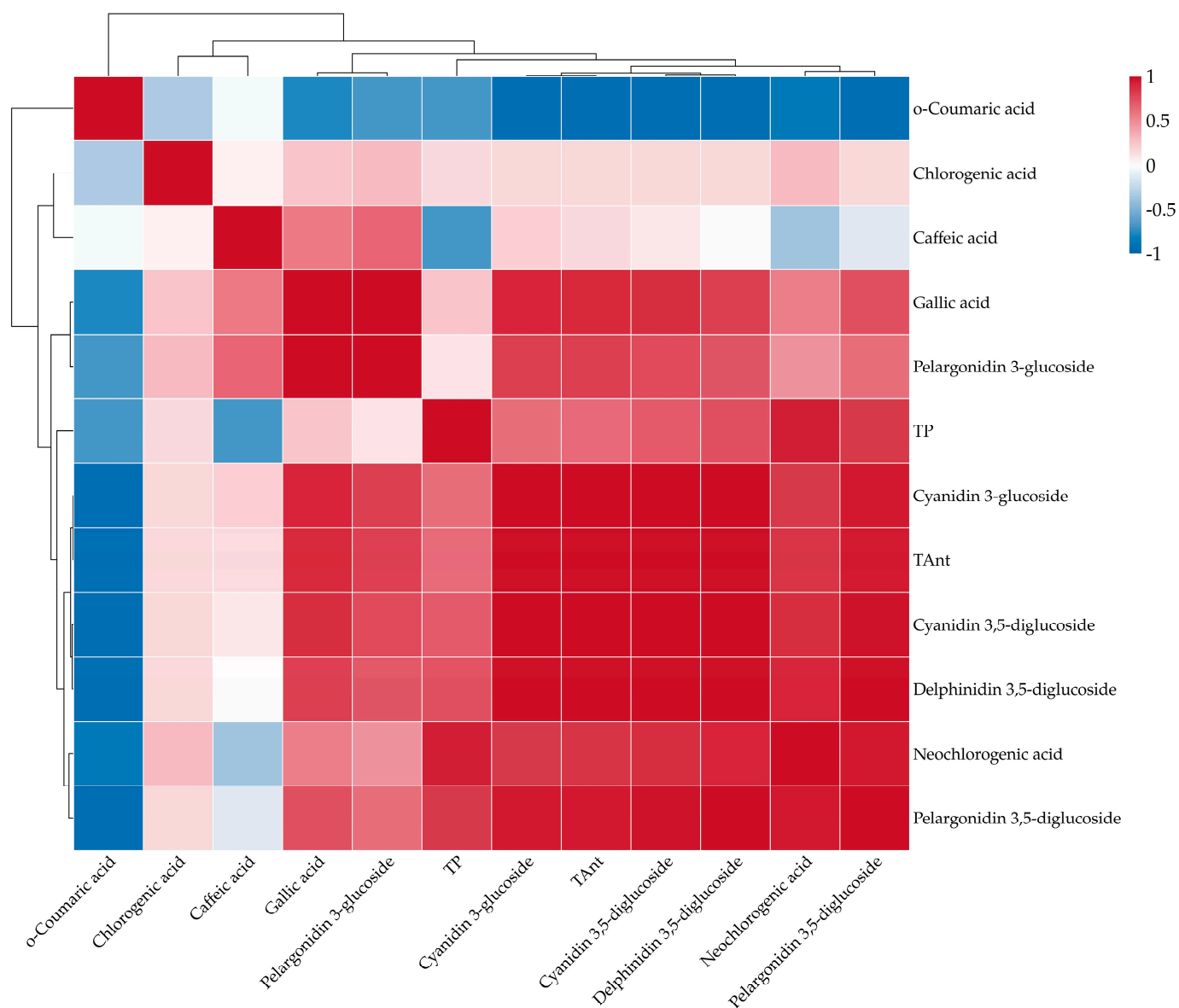


Figure 3. Pearson correlation heatmap of physicochemical parameters, bioactive compounds and color characteristics of pomegranate juices.

This study focused on compositional parameters (nutritional and functional quality), while consumer perception and sensory acceptability were not directly assessed. This difference is relevant and is confirmed by the results of a study by Mayuoni Kirshenbaum et al. [44], who reported that consumers tend to prefer juices with lower astringency and a milder sensory profile compared to juices obtained by pressing the whole fruit, which contain a higher content of phenols—especially hydrolyzable tannins. Future studies involving sensory evaluation by a trained panel and/or consumer acceptance testing with a target population would help clarify whether consumer preferences are primarily driven by the sensory properties or functional value of the product.

4. Conclusions

This study showed that sweet, sour, and sweet–sour pomegranate juices differ significantly in their physicochemical characteristics, bioactive composition, color parameters, and volatile profiles. The observed differences confirmed that cultivar type plays a major role in shaping juice quality, especially through the balance between solubles and acidity, the accumulation of bioactive phenolic compounds and anthocyanins, and the resulting color and aroma attributes. Among the analyzed samples, sweet–sour juice showed the most balanced overall profile, in terms of bioactive composition and physicochemical properties, making it particularly suitable for functional beverage applications. Our results suggest that blending juices from cultivars with contrasting flavor profiles may be an effective strategy for producing pomegranate beverages with improved functional value, organoleptic properties and desirable quality attributes. Future research should include a wider range of cultivars and sensory evaluation panels to further confirm and expand the results obtained in our study.

Author Contributions: Conceptualization, M.V.B., I.G.M. and M.R.; methodology, M.V.B., I.G.M., M.P. and M.R.; software, M.V.B., M.P.; validation, M.V.B., I.G.M., M.P. and M.R.; formal analysis, M.V.B., I.G.M., M.P. and M.R.; investigation, M.V.B., I.G.M., M.P. and M.R.; resources, I.G.M., M.R.; data curation, M.V.B., I.G.M., M.P. and M.R.; writing—original draft preparation, M.V.B.; writing—review and editing, M.V.B., I.G.M., M.P. and M.R.; visualization, M.V.B.; supervision, I.G.M. and M.R.; project administration, M.R.; funding acquisition, M.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Split-Dalmatia County (011-169/3-22) and Croatian National Program for Conservation and Sustainable Use of Plant Genetic Resources for Food and Agriculture 2021–2027 (01-181/2-17).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Acknowledgments: The authors are very thankful for the scientific research equipment financed by the EU grant “Functional integration of the University of Split, PMFST, PFST and KTFST through the development of the scientific and research infrastructure” (KK.01.1.1.02.0018).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Al-Said, F.A.; Opara, L.U.; Al-Yahyai, R.A. Physico-chemical and textural quality attributes of pomegranate cultivars (*Punica granatum* L.) grown in the Sultanate of Oman. *J. Food Eng.* **2009**, *90*, 129–134. [[CrossRef](#)]
2. Fawole, O.A.; Opara, U.L. Effects of maturity status on biochemical content, polyphenol composition and antioxidant capacity of pomegranate fruit arils (cv. ‘Bhagwa’). *S. Afr. J. Bot.* **2013**, *85*, 23–31. [[CrossRef](#)]
3. Mphahlele, R.R.; Fawole, O.A.; Mokwena, L.M.; Opara, U.L. Effect of extraction method on chemical, volatile composition and antioxidant properties of pomegranate juice. *S. Afr. J. Bot.* **2016**, *103*, 135–144. [[CrossRef](#)]
4. Viuda-Martos, M.; Fernández-López, J.; Pérez-Álvarez, J.A. Pomegranate and its many functional components as related to human health: A review. *Compr. Rev. Food Sci. Food Saf.* **2010**, *9*, 635–654. [[CrossRef](#)] [[PubMed](#)]
5. Miguel, M.G.; Neves, M.A.; Antunes, M.D. Pomegranate (*Punica granatum* L.): A medicinal plant with myriad biological properties—A short review. *J. Med. Plants Res.* **2010**, *4*, 2836–2847. [[CrossRef](#)]
6. Ben-Simhon, Z.; Judeinstein, S.; Trainin, T.; Harel-Beja, R.; Bar-Ya’akov, I.; Borochoy-Neori, H.; Holland, D. A “white” anthocyanin-less pomegranate (*Punica granatum* L.) caused by an insertion in the coding region of the leucoanthocyanidin dioxygenase (LDOX; ANS) gene. *PLoS ONE* **2015**, *10*, e0142777. [[CrossRef](#)] [[PubMed](#)]

7. Gómez-Caravaca, A.M.; Verardo, V.; Toselli, M.; Segura-Carretero, A.; Fernández-Gutiérrez, A.; Caboni, M.F. Determination of the major phenolic compounds in pomegranate juices by HPLC-DAD-ESI-MS. *J. Agric. Food Chem.* **2013**, *61*, 5328–5337. [[CrossRef](#)] [[PubMed](#)]
8. Radunić, M.; Jukić Špika, M.; Goreta Ban, S.; Gadže, J.; Díaz-Pérez, J.C.; MacLean, D. Physical and chemical properties of pomegranate fruit accessions from Croatia. *Food Chem.* **2015**, *177*, 53–60. [[CrossRef](#)] [[PubMed](#)]
9. Schwartz, E.; Tzulker, R.; Glazer, I.; Bar-Ya'akov, I.; Wiesman, Z.; Tripler, E.; Bar-Ilan, I.; Fromm, H.; Borochoy-Neori, H.; Holland, D.; et al. Environmental conditions affect the color, taste, and antioxidant capacity of 11 pomegranate accessions' fruits. *J. Agric. Food Chem.* **2009**, *57*, 9197–9209. [[CrossRef](#)] [[PubMed](#)]
10. Fernandes, L.; Pereira, J.A.; López-Cortés, I.; Salazar, D.M.; Ramalhosa, E.C.D. Physicochemical changes and antioxidant activity of juice, skin, pellicle and seed of pomegranate (cv. Mollar de Elche) at different stages of ripening. *Food Technol. Biotechnol.* **2015**, *21*, 397–406. [[CrossRef](#)] [[PubMed](#)]
11. Gil, M.I.; Tomás-Barberán, F.A.; Hess-Pierce, B.; Holcroft, D.M.; Kader, A.A. Antioxidant activity of pomegranate juice and its relationship with phenolic composition and processing. *J. Agric. Food Chem.* **2000**, *48*, 4581–4589. [[CrossRef](#)] [[PubMed](#)]
12. Tzulker, R.; Glazer, I.; Bar-Ilan, I.; Holland, D.; Aviram, M.; Amir, R. Antioxidant activity, polyphenol content, and related compounds in different fruit juices and homogenates prepared from 29 different pomegranate accessions. *J. Agric. Food Chem.* **2007**, *55*, 9559–9570. [[CrossRef](#)] [[PubMed](#)]
13. Li, X.; Wasila, H.; Liu, L.; Yuan, T.; Gao, Z.; Zhao, B.; Ahmad, I. Physicochemical characteristics, polyphenol compositions and antioxidant potential of pomegranate juices from 10 Chinese cultivars and the environmental factors analysis. *Food Chem.* **2015**, *175*, 575–584. [[CrossRef](#)] [[PubMed](#)]
14. Fischer, U.A.; Carle, R.; Kammerer, D.R. Thermal stability of anthocyanins and colourless phenolics in pomegranate (*Punica granatum* L.) juices and model solutions. *Food Chem.* **2013**, *138*, 1800–1809. [[CrossRef](#)] [[PubMed](#)]
15. Budiene, J.; Guclu, G.; Oussou, K.F.; Kelebek, H.; Selli, S. Elucidation of volatiles, anthocyanins, antioxidant and sensory properties of cv. Caner pomegranate (*Punica granatum* L.) juices produced from three juice extraction methods. *Foods* **2021**, *10*, 1497. [[CrossRef](#)] [[PubMed](#)]
16. Al-Maiman, S.A.; Ahmad, D. Changes in physical and chemical properties during pomegranate (*Punica granatum* L.) fruit maturation. *Food Chem.* **2002**, *76*, 437–441. [[CrossRef](#)]
17. Opara, L.U.; Al-Ani, M.R.; Al-Shuaibi, Y.S. Physico-chemical properties, vitamin C content, and antimicrobial properties of pomegranate fruit (*Punica granatum* L.). *Food Bioprocess Technol.* **2009**, *2*, 315–321. [[CrossRef](#)]
18. Teixeira da Silva, J.A.; Rana, T.S.; Narzary, D.; Verma, N.; Meshram, D.T.; Ranade, S.A. Pomegranate biology and biotechnology: A review. *Sci. Hortic.* **2013**, *160*, 85–107. [[CrossRef](#)]
19. Radunić, M.; Jukić Špika, M.; MacLean, D.; Díaz-Pérez, J.C. Microclimate condition influence on the physicochemical properties and antioxidant activity of pomegranate (*Punica granatum* L.): A case study of the east Adriatic coast. *Agriculture* **2025**, *15*, 2210. [[CrossRef](#)]
20. Veršić Bratinčević, M.; Kovačić, R.; Popović, M.; Radman, S.; Generalić Mekinić, I. Comparison of Conventional and Green Extraction Techniques for the Isolation of Phenolic Antioxidants from Sea Fennel. *Processes* **2023**, *11*, 2172. [[CrossRef](#)]
21. Kamal, Y.T.; Alam, P.; Alqasoumi, S.I.; Foudah, A.I.; Alqarni, M.H.; Yusufoglu, H.S. Investigation of antioxidant compounds in commercial pomegranate molasses products using matrix-solid phase dispersion extraction coupled with HPLC. *Saudi Pharm. J.* **2018**, *26*, 839–844. [[CrossRef](#)] [[PubMed](#)]
22. Tarhan, S. Selection of chemical and thermal pretreatment combination for plum drying at low and moderate drying air temperatures. *J. Food Eng.* **2007**, *79*, 255–260. [[CrossRef](#)]
23. Vázquez-Araújo, L.; Koppel, K.; Chambers, E.; Adhikari, K.; Carbonell-Barrachina, A.A. Instrumental and sensory aroma profile of pomegranate juices from the USA: Differences between fresh and commercial juice. *Flavour Fragr. J.* **2011**, *26*, 129–138. [[CrossRef](#)]
24. Tarantino, A.; Difonzo, G.; Disciglio, G.; Frabboni, L.; Paradiso, M.; Caponio, F. Fresh pomegranate juices from cultivars and local ecotypes grown in southeastern Italy: Comparison of physicochemical properties, antioxidant activity and bioactive compounds. *J. Sci. Food Agric.* **2021**, *102*, 1185–1192. [[CrossRef](#)] [[PubMed](#)]
25. Beaulieu, J.C.; Lloyd, S.W.; Preece, J.E.; Moersfelder, J.W. Physicochemical properties and aroma volatile profiles in a diverse collection of California-grown pomegranate (*Punica granatum* L.) germplasm. *Food Chem.* **2015**, *181*, 354–364. [[CrossRef](#)] [[PubMed](#)]
26. Rinaldi, M.; Caligiani, A.; Borgese, R.; Palla, G.; Barbanti, D.; Massini, R. The effect of fruit processing and enzymatic treatments on pomegranate juice composition, antioxidant activity and polyphenols content. *LWT Food Sci. Technol.* **2013**, *53*, 355–359. [[CrossRef](#)]
27. Mena, P.; García-Viguera, C.; Navarro-Rico, J.; Martínez, N.; Moreno, D.A. Phytochemical characterisation for industrial use of pomegranate (*Punica granatum* L.) cultivars grown in Spain. *J. Sci. Food Agric.* **2011**, *91*, 1893–1906. [[CrossRef](#)] [[PubMed](#)]
28. Rajasekar, D.; Akoh, C.C.; Martino, K.G.; MacLean, D.D. Physico-chemical characteristics of juice extracted by blender and mechanical press from pomegranate cultivars grown in Georgia. *Food Chem.* **2012**, *133*, 1383–1393. [[CrossRef](#)]

29. Akhavan, H.; Barzegar, M.; Weidlich, H.; Zimmermann, B.F. Phenolic compounds and antioxidant activity of juices from ten Iranian pomegranate cultivars depend on extraction. *J. Chem.* **2015**, 907101. [\[CrossRef\]](#)
30. Mottaghipisheh, J.; Ayanmanesh, M.; Babadaye-Samani, R.; Javid, A.; Sanaeifard, M.; Vitalini, S.; Iriti, M. Total anthocyanin, flavonoid, polyphenol and tannin contents of seven pomegranate cultivars grown in Iran. *Acta Sci. Pol. Technol. Aliment.* **2018**, *17*, 211–217. [\[CrossRef\]](#) [\[PubMed\]](#)
31. Di Stefano, V.; Pitonzo, R.; Novara, M.E.; Bongiorno, D.; Indelicato, S.; Gentile, C.; Avellone, G.; Bognanni, R.; Sarrica, S.; Muccilli, V.; et al. Antioxidant activity and phenolic composition in pomegranate (*Punica granatum* L.) genotypes from South Italy by UHPLC-Orbitrap-MS approach. *J. Sci. Food Agric.* **2019**, *99*, 1038–1045. [\[CrossRef\]](#) [\[PubMed\]](#)
32. Esposto, S.; Veneziani, G.; Taticchi, A.; Urbani, S.; Selvaggini, R.; Sordini, B.; Daidone, L.; Gironi, G.; Servili, M. Chemical composition, antioxidant activity, and sensory characterization of commercial pomegranate juices. *Antioxidants* **2021**, *10*, 1381. [\[CrossRef\]](#) [\[PubMed\]](#)
33. Singh, B.; Singh, J.P.; Kaur, A.; Singh, N. Phenolic compounds as beneficial phytochemicals in pomegranate (*Punica granatum* L.) peel: A review. *Food Chem.* **2018**, *261*, 75–86. [\[CrossRef\]](#) [\[PubMed\]](#)
34. Saparbekova, A.A.; Kantureyeva, G.O.; Kudasova, D.E.; Konarbayeva, Z.K.; Latif, A.S. Potential of phenolic compounds from pomegranate (*Punica granatum* L.) by-product with significant antioxidant and therapeutic effects: A narrative review. *Saudi J. Biol. Sci.* **2023**, *30*, 103553. [\[CrossRef\]](#) [\[PubMed\]](#)
35. Ruan, J.-H.; Li, J.; Adili, G.; Sun, G.-Y.; Abuduaini, M.; Abdulla, R.; Maiwulanjiang, M.; Aisa, H.A. Phenolic compounds and bioactivities from pomegranate (*Punica granatum* L.) peels. *J. Agric. Food Chem.* **2022**, *70*, 3678–3686. [\[CrossRef\]](#) [\[PubMed\]](#)
36. Karakaplan, M.; Özcan, M. Determination of phenolic acids in pomegranate juices by HPLC-DAD. *Eur. J. Sci. Technol.* **2017**, *6*, 32–37.
37. Kähkönen, M.P.; Heinonen, M. Antioxidant Activity of Anthocyanins and Their Aglycons. *J. Agric. Food Chem.* **2003**, *51*, 628–633. [\[CrossRef\]](#) [\[PubMed\]](#)
38. Türkyılmaz, M.; Hamzaoglu, F.; Arı Çiftci, R.B.; Özkan, M. Increase in Colour Stability of Pomegranate Juice against 5-Hydroxymethylfurfural (HMF) through Copigmentation with Phenolic Acids. *J. Sci. Food Agric.* **2023**, *103*, 7836–7848. [\[CrossRef\]](#) [\[PubMed\]](#)
39. Enaru, B.; Dreţcanu, G.; Pop, T.D.; Stănilă, A.; Diaconeasa, Z. Anthocyanins: Factors Affecting Their Stability and Degradation. *Antioxidants* **2021**, *10*, 1967. [\[CrossRef\]](#) [\[PubMed\]](#)
40. Peng, Y.; Yun, Y.; Zou, W.; Zhou, L. Characterisation of colour, phenolics, and volatile compounds of six pomegranate varieties grown in Yunnan. *Int. J. Food Sci. Technol.* **2025**, *60*, vvaf007. [\[CrossRef\]](#)
41. Koppel, K.; Anderson, E.L.; Chambers, E. Influence of processing on pomegranate (*Punica granatum* L.) juice flavor and aroma. *J. Sci. Food Agric.* **2014**, *95*, 1066–1071. [\[CrossRef\]](#) [\[PubMed\]](#)
42. Beaulieu, J.C.; Stein-Chisholm, R.E. HS-GC-MS volatile compounds recovered in freshly pressed ‘Wonderful’ cultivar and commercial pomegranate juices. *Food Chem.* **2016**, *190*, 643–656. [\[CrossRef\]](#) [\[PubMed\]](#)
43. Perestrelo, R.; Silva, C.; Silva, P.; Medina, S.; Câmara, J.S. Differentiation of fresh and processed fruit juices using volatile composition. *Molecules* **2019**, *24*, 974. [\[CrossRef\]](#) [\[PubMed\]](#)
44. Mayuoni Kirshenbaum, L.; Benjamin, O.; Porat, R. Sensory and nutritional attributes of pomegranate juices extracted from separated arils and pressed whole fruits. *J. Sci. Food Agric.* **2016**, *96*, 1313–1318. [\[CrossRef\]](#) [\[PubMed\]](#)

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.