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Biochemical, Morphostructural, and Statistical Rationale for the Flavor Classification and Selection of Juice-Processing Cultivars of *Punica granatum L.*

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Abstract

This article presents a comprehensive biochemical, morphostructural, and statistical rationale for the flavor classification and selection of promising juice-processing pomegranate (*Punica granatum L.)* cultivars from the Goychay collection of the Research Institute of Fruit and Tea Growing of the Ministry of Agriculture of the Republic of Azerbaijan. Gravimetric and chemical analyses were used to investigate the formation of the carbohydrate–acid complex and the accumulation dynamics of structural fruit components during ripening. Across 32 cultivar accessions, sugars were represented predominantly by invert sugars (12.35% on average) with a minimal proportion of sucrose (0.48% on average). Flavor differentiation is driven primarily by a fourfold decrease in titratable acidity-from 2.31% in the sour group to 0.56% in the sweet group-and by shifts in the sugar–acid index (SAI) from 3.99 to 23.77. The high coefficient of variation for SAI (CV = 98.62%) confirms substantial biochemical diversity, enabling targeted breeding for both fresh consumption and industrial processing. For the first time, a separate evaluation of 25 cultivars and forms revealed three distinct patterns of fruit structural development during ripening: (1) predominant mass accumulation of solid parts (peel and seeds) over juice, (2) uniform growth of both solid fractions and juice, and (3) accelerated accumulation of the juice fraction outpacing solid tissues, which ensures superior raw-material quality with maximum juice recovery. Furthermore, statistical analysis established for the first time that medium-fruited cultivars achieve a significantly higher juice yield (53.2 ± 5.3%) than small-fruited (45.4 ± 7.0%) and large-fruited (43.1 ± 5.7%) cultivars. These findings provide a critical benchmark for selecting economically viable raw materials for the juice industry and enhancing the efficiency of pomegranate breeding programs.

1 INTRODUCTION

Pomegranate (Punica granatum L.) has established itself as a functional food that is attracting growing interest, both from an economic perspective and within the scientific community. This has led to a substantial increase in publications devoted mainly to its characteristics, benefits, and nutritional composition [1–3].

The high nutritional value of the fruit is due to its rich content of biologically active compounds, including polyphenols, anthocyanins, organic acids, and soluble sugars. However, the organoleptic properties of pomegranate juice-from distinctly sour to cloyingly sweet-vary considerably depending on the genotype, soil and climatic conditions, and degree of fruit maturity [4].

At present, the assessment of the flavor quality of cultivars often relies on subjective tasting or is limited to determining the basic sugar-acid index (SAI), which does not always accurately reflect the complex sensory perception of the product by consumers. As industrial juice production expands and requirements in the fresh market increase, there is a need for objective, reproducible criteria for selecting cultivar material. The use of multivariate statistical methods in combination with detailed biochemical profiling makes it possible to eliminate subjectivity in assessment and establish reliable correlations between the chemical composition of juice and its flavor characteristics.

The aim of the study was to classify the flavor of pomegranate juice, identify key biochemical indicators, and select promising cultivars for the fresh market and processing.

2 MATERIALS AND METHODS

The study was conducted in 2022–2023 in accordance with the Methodology for Chemical and Technological Variety Testing, approved by the Scientific Council of the Research Institute of Fruit and Tea Growing of the Ministry of Agriculture of the Republic of Azerbaijan.

2.1 Research objects

The research material consisted of fruits of pomegranate cultivars and forms from the collection of the above-mentioned institute in Goychay.

Since morpho-technological traits are responsive to the climatic conditions of each year, fruits at harvest maturity were collected for two consecutive years, 2022–2023. Only fruits that had set during the first half of the pomegranate flowering period, which peaks from mid-May to early June, were selected. This is because fruits set on current-year shoots during the second half of the overall flowering period (which here begins on 25 June and ends on 10 July) are underdeveloped fruits with a certain lag in growth and development.

2.2 Subject and principles of the study

The subject of the study was the scientific and methodological substantiation of the biochemical differentiation and statistical classification of pomegranate cultivars and forms according to flavor indicators and juice yield.

A representative sample of 50 typical fruits of each cultivar was collected from mature trees for mechanical and biochemical analyses.

Pomegranate juices (the “directly pressed” category) were obtained by manually separating the fruits and pressing the separated pomegranate arils in a laboratory press. Before chemical analysis, the freshly squeezed juices were centrifuged at g = 2500 for 5 minutes to remove large insoluble particles.

2.3 Regional conditions and location of the collection plot

The collection plot is located on the grounds of a field station near the town of Goychay, which is situated in the central part of Azerbaijan, in the Shirvan Plain, at a road junction and approximately 216–219 km from Baku.

In the Goychay district, the soils are mainly light-brown and meadow-type, while annual precipitation ranges from 220 to 443 mm and the sum of active temperatures ranges from 4445 to 45500 C. Here, 10–15 days pass from bud formation to flower opening, and flowering most often begins on 05.05.

Pomegranate fruits set during the first half of the main flowering period on branches older than one year account for approximately 60–70% of the total harvest.

2.4 Selection of a composite sample and specimens for chemical analyses

When selecting a composite fruit sample for chemical analyses, procedures are followed to ensure the objectivity and representativeness of the results. To obtain a sample of 50 fruits, they are collected evenly from 5–10 trees (usually from at least 5 trees of the same pomological cultivar). Trees are selected diagonally or in a staggered pattern. Fruits must not be collected only from the outermost trees or only from diseased trees.

From each tree, 5–10 fruits are collected from different parts of the canopy (inner and outer), from all four cardinal directions (north, south, east, and west), and from different canopy levels (upper, middle, and lower). The fruits should be of different sizes, typical of the cultivar in question.

A composite sample is formed from the initial sample (50 fruits).

For analysis, 10–20 fruits (or approximately 1–2 kg) are selected that most accurately reflect the characteristics of the entire batch.

In the sampling procedure, all 50 fruits are arranged in a row according to size or degree of maturity, after which every second, third, or fourth fruit is selected (the mechanical sampling method) until the required number is reached (for example, 15 fruits).

The selected fruits are first separated manually into peel and arils; juice is then extracted from the arils using a laboratory press.

The analytical sample is a precisely measured quantity of juice (usually 5 to 50 grams), which is prepared as follows.

The fruits selected for analysis (10–20 pieces) are washed, dried with filter paper, shallowly cut at the surface into several segments, and the arils are manually separated from the peel (the leathery pericarp plus the light, spongy membranes).

The juice is then pressed from the individual arils using a laboratory press.

An aliquot of freshly squeezed juice is weighed using analytical or precision balances with an accuracy of 0.01 g or 0.001 g.

2.5 Methods for assessing chemical composition

Soluble solids (TSS) were determined in accordance with ISO 2173 – 2013 (ISO 2173 – 2013, 2019). The concentration is measured using digital refractometers (based on light refraction) in grams per 100 g or

in degrees Brix (°Bx); 1 degree Brix is equivalent to 1 gram of sucrose in 100 grams of solution (at the standard temperature of 20°C).

Sugars (reducing sugar, sucrose, and total sugar) were determined by the Bertrand method (GOST 8756.13-87, 2010).

Titratable acidity was determined in accordance with ISO 750–2013, 2018.

Mechanical analyses were performed using Mettler Toledo analytical balances with a resolution of 0.01 gram.

2.6 Processing of primary data

Each physical and chemical indicator was determined in three parallel replicates. The combined data for each parameter from the two years of research were subjected to statistical analysis using the Statistica 10.0 software package.

3 RESULTS AND DISCUSSION

2.2.1. Biochemical differentiation and statistical classification of 32 pomegranate cultivars and forms according to flavor indicators
In pomegranate cultivation in Azerbaijan and Turkey, there is an established tradition of dividing local cultivars into three categories: sweet, sweet-and-sour, and sour [5]. Each of these groups includes early-, mid-, and late-ripening cultivars, making it possible to harvest in the Mediterranean region over three periods, from 20 August to 20 October [6].

Although this division is based on subjective taste perceptions, it has a clear biochemical basis-the differences in the sugar-acid index (SAI). Using cultivars from the collection of the Goychay Experimental Station of the Research Institute of Fruit and Tea Growing as an example, we will trace how the ratio of sugars to organic acids determines whether a cultivar belongs to one flavor group or another.

An analysis of the data in Table 2 makes it possible to draw the scientifically grounded conclusion that pomegranate flavor is determined not so much by the total amount of sugars as by the level of acidity and the sugar-acid index (SAI). The difference in sugar content between sour and sweet cultivars is only 1.52%, whereas the acid content differs by more than fourfold.

The SAI values in the table are not obtained by directly dividing the mean values (for example, 11.79 / 2.31 = 5.10, whereas the table gives 3.99). This is entirely correct statistically if the SAI was first calculated separately for each cultivar and the arithmetic mean was then calculated for the group.

Table 2
– Biochemical indicators of carbohydrate composition and acidity in juices from different pomegranate flavor groups in Goychay.

Pomological cultivar / form	TSS content, %	Invert sugar, %	Sucrose, %	Total sugars, %	Titratable acidity (as citric acid), %	SAI*
1. Sour cultivars and forms (n = 5)						
Kaim Nar	14,2	9,93	0,11	10,04	4,61	2,18
Shelli Melesi	14.6	12.77	1.58	14.35	3,00	4,78
Shah Nar	15.8	11.35	0.38	11.73	2.93	4,00
Yeni Guleisha	13.8	11.70	0.22	11.92	2.50	4,77
Mardakyanly	14.0	10.61	0.23	10.89	2.57	4,24
Group mean	**14,5**	**11,27**	**0,50**	**11,77**	**2,31**	**3,99**
2. Sweet-and-sour cultivars and forms (n = 21)						
Nazik Kabukh	18.1	12. 37	0.49	12.86	2.52	5,10
Guleisha Red	18.4	13.64	0.82	14.47	1.64	8,82
Guleisha Pink	16.2	12.27	0.99	13.26	1.82	7,29
Bala Mursal	15.8	13.09	0.63	13.51	1.91	7,07
Kirmyzy Kabukh	15.6	12.80	0.36	13.16	1.98	6,65
VIR-1	15.8	12.87	0.14	13.01	2.03	6,41
Iran 36 − 1	15.2	13.44	0.92	14.36	1.62	8,86
Iran 9 − 4	15.7	14.25	0.14	14.39	1.63	8,83
Iran 20 − 4	16.0	12.80	0.31	13.11	1.60	8,19
Iran 10 − 4	14.6	12.59	0.74	13.33	1.28	10,41
Iran 4 − 1	15.0	12.80	0.50	13.30	1.55	8,58
Kazake	15.0	11.81	0.14	11.95	2.11	5,66
Sulu Nar	13.6	11.35	0.50	11.85	2.50	4,74
Shirvan	14.4	11.27	0.11	11.38	3.51	3,24
Rubin	16.6	13.54	0.07	13.61	2.07	6,57
Iridanaly	15.0	11.49	0.18	11.75	1.89	6,22

Note: TSS – total soluble solids; SAI* – sugar-acid index.*

Pomological cultivar / form	TSS content, %	Invert sugar, %	Sucrose, %	Total sugars, %	Titratable acidity (as citric acid), %	SAI*
Meykhosh	14.8	11.76	0.35	12.11	1.85	6,55
Aleko	15.1	12.34	0.17	12.52	2.57	4,87
Improved Kazake	15.0	11.51	0.29	11.80	2.03	5,81
Meskheti	14.0	11.81	0.32	12.13	1.94	6,25
Irada	17.0	13.27	0.34	13.61	1.44	9,45
Group mean	**15,6**	**12,53**	**0,41**	**12,93**	**1,98**	**7,27**
3. Sweet cultivars and forms (n = 6)						
Malta	13.0	11.45	1.25	12.70	0.37	34,32
Vostorg	13.4	12.31	0.29	12.60	0.57	22,11
Aresh	16.0	14.50	0.73	15.23	0.41	37,15
Vesna	13.2	11.60	0.03	11.63	0.46	25,28
Farash	15.8	13.81	0.69	14.51	0.73	19,88
Bumazhny	14.2	11.94	1.26	13.20	0.50	26,40
Group mean	**14,27**	**12,60**	**0,71**	**13,31**	**0,56**	**23,77**
Mean for all cultivars and forms (n = 32)	15,2	12,35	0,48	12,83	1,88	9,85
Note: TSS – total soluble solids; SAI* – sugar-acid index.*						

A structured analysis of the indicators based on the data in Table 3 shows that the main factor separating cultivars into flavor groups is titratable acidity. In sour cultivars, this indicator reaches 2.31%, while in sweet cultivars it falls to 0.56%.

Table 3
Summary comparison of flavor groups.

Indicator	Sour cultivars and forms (n = 5)	Sweet-and-sour cultivars and forms (n = 21)	Sweet cultivars and forms (n = 6)	Collection mean
TSS, %	14,50	15,60	14,27	15,20
Invert sugar, %	11,27	12,53	12,60	12,35
Sucrose, %	0,50	0,41	0,71	0,48
Total sugars, %	11,79	12,93	13,31	12,83
Titratable acidity, %	2,31	1,98	0,56	1,88
Sugar-acid index	3,99	7,27	23,77	9,85

The total sugar content varies within a narrow range, from 11.79% to 13.31%. Even sour pomegranates contain a considerable amount of sugars, but their flavor is completely masked by the high concentration of citric acid.

The main proportion of carbohydrates in all groups consists of monosaccharides (invert sugar), which account for approximately 95–97% of the total sugars. The sucrose content is insignificant and is less than 1%, reaching its maximum in sweet cultivars (0.71%).

The SAI serves as the most accurate integrated indicator of flavor. When moving from sour cultivars to sweet-and-sour cultivars, the index almost doubles (from 3.99 to 7.27), while in sweet cultivars it rises sharply to 23.77.

The highest TSS content was recorded in the sweet-and-sour group (15.6%). This is explained by the fact that the TSS indicator includes both the high sugar content of this group (12.93%) and its relatively high acidity (1.98%).

The overwhelming majority of the cultivars and forms studied (21 out of 32, or 65.6%) belong to the sweet-and-sour group. This reflects the region's natural breeding orientation toward obtaining cultivars with a harmonious, balanced flavor.

In biometrics, the following scale is used to assess variability by the coefficient of variation (CV):

- • less than 10% - low variability (the trait is stable);
- • from 10 to 20% -moderate variability;
- • more than 20% -high variability (the trait varies considerably).

The results of the statistical analysis of the chemical-composition indicators of the juices obtained by direct pressing of the fruits of the studied pomegranate accessions are presented in Table 4.

Table 4
– Descriptive statistics of the biochemical indicators of carbohydrate composition and acidity in directly pressed pomegranate juices from the Goychay collection (n = 32).

Biochemical indicators	**Min – Max**	$\bar{X}$	***SE***	***SD***	***CV***
TSS, %	13,00–18,10	15,2	± 0,22	1,25	8,22
Invert sugar, %	9,93 – 14,50	12,35	± 0,18	1,02	8,26
Sucrose, %	0,03 – 1,58	0,48	± 0,08	0,43	89,58
Total sugars, %	10,04–14,51	12,83	± 0,21	1,17	9,12
Titratable acidity, %	0,37 – 4,61	1,88	± 0,16	0,91	48,40
Sugar-acid index	3.99–23.77	9,85	± 1,72	9,71	98,62

Note: Min–Max - variation limits (range of changes); $\bar{X}$ - arithmetic mean; SE -standard error of the mean; SD - root mean square (standard) deviation; CV - coefficient of variation.

It was established that the sample under study is heterogeneous in terms of the degree of variation of the main components of its chemical composition.

The most stable indicators within the Goychay collection were the mass fraction of total soluble solids (TSS), invert sugar content, and total sugar content. The coefficients of variation for these traits were low and amounted to 8.22%, 8.26%, and 9.12%, respectively. At the same time, the main share of the carbohydrate complex (96.3% of total sugars on average) is formed by reducing (invert) sugars, whose content varied within a narrow range from 9.93% to 14.50%, with a mean value of 12.35 ± 0.18%.

At the same time, sucrose content and titratable acidity showed an extremely high degree of variability (CV = 89.58% and 48.40%, respectively).

The proportion of sucrose in the juices was insignificant (0.48 ± 0.08% on average); however, its range of variation was the largest among all the indicators studied-from trace amounts (0.03%) to 1.58%. The considerable variation in titratable acidity (from 0.37% to 4.61%) indicates the broad genetic diversity of the collection, which includes sweet, sweet-and-sour, and sour pomegranate forms.

The sugar-acid index (SAI) values in the table indicate the exceptionally broad flavor diversity of the pomegranate cultivars studied-from very sour processing accessions to cloyingly sweet dessert fruits. On average, cultivars with a harmonious sweet-and-sour flavor predominate in the collection.

The sugar-acid index is the ratio of total sugars to titratable acidity and is the main objective criterion for assessing the flavor quality of fruits and juices.

Its mean value ($\bar{X}$ = 9.85) characterizes the average profile of the collection as sweet-and-sour (closer to dessert-type). This balance is considered optimal for fresh consumption and the production of high-quality directly pressed juices.

At the same time, the range between the minimum and maximum SAI values (Min–Max = 3.99–23.77) is almost sixfold. This indicates the presence of three clearly defined pomegranate flavor groups in the Goychay collection:

Sour cultivars (SAI around 4–6) have a high acid content (up to 4.61%). They are less suitable for fresh consumption but are highly valuable for processing (for example, for producing the traditional pomegranate sauce narsharab or citric acid).

Sweet-and-sour cultivars (SAI around 7–15) represent the gold standard among table cultivars, with a refreshing, balanced flavor.

Sweet cultivars (SAI above 15–20) have fruits with minimal acidity (from 0.37%), distinguished by pronounced sweetness and a mild flavor without sharp sourness.

The coefficient of variation of the SAI (CV = 98.62%) indicates a high level of variability (in statistics, variability is considered high already at CV > 30%). This value indicates that the sample of 32 accessions is extremely heterogeneous in terms of flavor.

A comparison of the table data shows that SAI variability is caused not so much by fluctuations in sugars (CV = 9.12%) as by the enormous difference in organic acid content (CV = 48.40%). In other words, sugar content is relatively stable among different pomegranate cultivars, while the final flavor of the fruit is determined precisely by its acidity level.

The identified variability in acidity, combined with the relative stability of sugar accumulation, makes it possible to identify promising genotypes within the collection for various processing applications: from producing directly pressed juices with a harmonious flavor to obtaining concentrated juices and natural acidifiers.

Researchers emphasize that fruit flavor can be used as a reference trait when selecting cultivars for fresh consumption or industrial processing [7].

2.2.2. Grouping cultivar accessions according to the ratio of juice yield to inedible fruit components and the patterns of its formation

The key characteristics for the fresh pomegranate market are fruit size and peel thickness, which play an important role in consumer and market selection [8].

Cultivars whose fruits contain up to 48.5% juice by total fruit weight and have a high content of soluble solids (TSS-TSS or Brix) not below the established threshold (> 12%) are classified as good products for the market and juice production [9–10].

It is believed that fruits with a thin peel and, consequently, a lower peel percentage are more suitable for processing, whereas fruits with a thicker peel and a higher peel percentage are more suitable for transportation and storage and may therefore be used for fresh consumption [11].

In the fruits of 10 pomegranate cultivars grown in Iran, the percentages of peel / juice / and seeds varied within the ranges of 33.4 ± 9.0–46.2 ± 9.0 / 53.3 ± 12.0–66.6 ± 7.0 / and 29.0 ± 5.0–48.7 ± 6.0, respectively; only two cultivars had a juice percentage of 48 or higher [12].

In ripe fruits of pomegranate cultivars grown in open fields in southern Italy, the juice percentage varied from 37 (*Kamel* cultivar) to 46 (*Ako* cultivar), while the percentages of dehulled seeds and peel were 31–40% and 22–23%, respectively [13].

A significant positive correlation was observed between seed hardness and juice content in pomegranate arils: cultivars with less hard dehulled seeds contained more juice per unit mass of arils than cultivars with harder seeds [14].

In 37 pomegranate cultivars from seven provinces of China, the mass of fruits / arils / and seeds, depending on the cultivar, varied within the ranges of 210.5–576.5 g / 121.0–327.5 g / and 1.80–3.41 g, respectively. Fruit height varied within 10.51–15.48 mm, diameter within 11.46–17.50 mm, peel thickness within 2.14–6.98 mm, shape index within 0.82–0.96, and seed number within 249.1–838.9. The coefficients of variation of the studied traits ranged from 5.62 to 54.02%. The proportion of arils in the total fruit mass varied from 42.58 to 64.83%. Based on the overall assessment, it was concluded that only some cultivars are suitable for juice processing [7].

Another study [15] showed that fruit weight is the strongest indicator determining critical differences between cultivars, with fruit weight being positively correlated with fruit peel thickness (r = + 0.11).

A study [16] devoted to the morphological variability of pomegranate cultivars from the central regions of Algeria concluded that, in pomegranate, fruit mass is statistically positively correlated with the mass of the peel and membranes. In fact, this means that the smaller the fruit mass, the lower the mass of the peel and membranes; as the mass of the solid parts decreases, the likelihood that the proportion of juice in the total fruit mass will increase becomes greater.

Thus, published studies show that although Punica granatum is a typical juicy-seeded plant, its fruits contain less juice than might be desired, and obtaining juice amounting to 48% of the total fruit mass can be considered a good result. Achieving more is difficult without clearly defined criteria to guide efforts to obtain more juice per unit of processed raw material and to carry out early screening of breeding material. Without such criteria, the development of new pomegranate cultivars for juice is often mixed with the development of new pomegranate cultivars for dessert use, although these may be entirely different tasks that should be addressed using different starting material. Therefore, it is particularly important to follow sound principles both when selecting raw material for juice from existing cultivars and when breeding new table and juice cultivars.

In this regard, we conducted a separate experiment, which showed that the mass of an individual ripe fruit of the cultivars *Vesna*, *Iridanaly, Guleisha Pink*, and *Wild Pomegranate* ranged from 130 g (Wild Pomegranate) to 288 g (Guleisha Pink). Of this, 60–113% was peel, 53–140% was juice, and 17–85% was dehulled seeds.

When studying the pattern of formation of the ratio between the above-mentioned fruit components, it was found that, over the period from 20 July to 15 October, the juice proportion in the sweet-and-sour fruits of *Guleisha Pink*, the slightly sweet pomegranates of *Iridanaly*, and the sour *Wild Pomegranate* increased from 38.9%, 47.4%, and 27.9% to 48.6%, 54.0%, and 40.8%, respectively; in contrast, in the sweet cultivar *Vesna* it decreased from 46.4% to 42.9% (Fig. 1).

In the cultivars *Guleisha Pink*, *Iridanaly*, *Vesna*, and *Wild Pomegranate*, over the above-mentioned period, the proportion of peel (leathery pericarp + membranes) in the total fruit mass decreased from the initial values of 44.2 / 35.7 / 35.7 / and 53.5% to the final values of 39.2 / 28.0 / 26.8 / and 46.2%, respectively.

The situation was different with regard to the percentage of seeds left exposed after the juice was pressed from the juicy arils in the laboratory press.

At the end of the second decade of July, the percentage of dehulled seeds in *Guleisha Pink* and *Wild Pomegranate* was 16.8 and 18.6, respectively; by mid-October, it had decreased to 12.8 and 13.1. In contrast, in *Iridanaly* and *Vesna* it increased from 16.9 and 17.9 at the end of the second decade of July to 18.0 and 30.4 by mid-October.

Over the same period, the peel mass per fruit of these cultivars and *Wild Pomegranate* increased as follows: *Guleisha Pink*-from 42 g to 113 g, or 2.7 times; *Wild Pomegranate*-from 23 g to 60 g, or 2.6 times; *Iridanaly*-from 55 g to 70 g, or 2.7 times; *Vesna*-from 50 g to 75 g, or 2.6 times.

The amount of dehulled seeds per fruit of these cultivars and Wild Pomegranate also increased over the same period: *Guleisha Pink*-from 16 g to 37 g, or 2.3 times; *Wild Pomegranate*-from 8 g to 17 g, or 2.1 times; *Iridanaly*-from 26 g to 45 g, or 1.7 times; *Vesna*-from 25 g to 85 g, or 3.4 times.

During this entire period, both the total fruit mass and the mass of the juice it contained increased considerably.

The mass of an individual fruit of the *Guleisha Pink* cultivar increased from 95 g to 288 g (a difference of 193 g), while the juice mass increased from 37 g to 140 g (that is, by 3.8 times).

The mass of an individual fruit of *Vesna* and *Wild Pomegranate* increased by 96 g and 87 g, respectively (from 154 g to 250 g and from 43 g to 130 g), while the juice mass increased by 55 g and 41 g (from 65 g to 120 g and from 12 g to 53 g, respectively, or by 1.8 and 4.4 times); in Iridanaly, fruit mass increased by 96 g (from 154 g to 250 g), and juice mass increased from 73 g to 135 g (that is, by 1.8 times).

These figures indicate that, during ripening and development on the tree, juice accumulation in the sweet-and-sour *Guleisha Pink* pomegranates and in *Wild Pomegranate* fruits occurred several times faster than in the slightly sweet Iridanaly cultivar and the sweet *Vesna* cultivar.

Nevertheless, owing to the lowest growth rates in the mass of peel and dehulled seeds, the juice percentage in *Iridanaly* by mid-October (54.0) was higher than in *Guleisha Pink*, *Vesna*, and *Wild Pomegranate* (40.8, 42.9, and 40.8, respectively).

Table 5 presents the morpho-technical characteristics of fruits at harvest maturity from 25 cultivars and forms in the same pomegranate collection. Among them, *Prevoskhodny*, *Shirin Nar*, *Vesna*, *California 630*, and *Malta* are sweet cultivars, while all the other cultivars and forms are sweet-and-sour.

Table 5
– Mass of an individual fruit and its parts in different pomegranate cultivars and forms from the Goychay collection.

Pomegranate cultivar and form	F	Lp	P	G	Bs	J	
						g	%
1. Small-fruited							
Azerbaijan	147	47	11	89	24	65	44,2
Veles Clone	160	65	16	79	11	68	42,5
Hybrid 2 × 2-9-5	182	50	15	117	10	107	58,6
Prevoskhodny	184	64	30	90	20	70	38,1
Yeni Guleisha	190	57	26	107	19	88	46,3
Guleisha Pink Clone	203	57	23	123	23	100	49,3
Hybrid 18	215	85	22	108	24	84	39,5
μ1	183± 23,5	60,7± 12,6	20,4± 6,7	101,8± 15,1	18,7± 5,9	83,1± 17,5	45,4± 7,0
2. Medium-fruited							
Meykhosh	220	78	10	132	29	103	46,8
Mardakyanly 20	222	72	10	140	20	120	54,1
Kirmyzy Kabukh	225	43	12	170	32	138	61,3
California 630	232	78	14	140	21	119	51,3
Irada	238	53	15	170	45	125	52,5
μ2	227,4± 7,5	64,8± 15,9	12,2± 2,3	150,4± 18,2	29,4± 10,1	121,0± 12,6	53,2± 5,3
3. Large-fruited							
Bala Mursal	242	75	28	139	31	108	44,6
Iridanaly	250	50	20	180	45	135	54,0
Malta	257	50	12	195	77	118	45,9
Siyah Dane	272	82	34	156	36	120	44,1
Guleisha Red	280	90	29	161	19	142	50,7
Vesna	280	50	25	205	85	120	42.9

Pomegranate cultivar and form	F	Lp	P	G	Bs	J	
						g	%
Bala Mursal Clone	284	118	24	142	28	114	40,1
Guleisha Pink	288	85	25	178	38	140	48,6
Shirin Nar	293	80	33	180	85	95	32,4
Nukhin Red	293	68	35	190	57	133	45,4
Iranian 3 – 1	306	113	50	143	26	117	38,2
Improved Kazake	324	113	34	177	44	133	41,0
VIR-1	400	153	54	193	43	150	36,5
μ3	289,9± 36,0	86,7± 29,1	31,0± 10,9	172,2± 20,7	47,2± 21,4	125,0± 14,8	43,1± 5,7
μ1–3	247,6± 26,8	75,0± 21,8	24,3± 8,0	148,1± 18,6	35,7± 14,8	112,5± 15,1	45,5± 6,0

Symbols: F – fruit; Lp – leathery pericarp; P – membranes; G – arils; Bs – dehulled seeds; J – juice.

In this table, pomegranate cultivars and forms are divided into three groups according to fruit mass. The first group comprises fruits weighing 147…215 g, the second 220…238 g, and the third 242…400 g.

This provides a clearer picture of how an increase or decrease in total fruit mass affects the juice yield from the fruit.

The table shows that the juice percentage in small-fruited cultivars and forms (fruit mass 147…215 g) and large-fruited cultivars (fruit mass 242…400 g) is much lower than in medium-fruited cultivars (fruit mass 220…238 g).

Juice yield as a percentage of total fruit mass was: 45.4 in the group with fruit mass from 147 to 215 g; 53.2% in the group with fruit mass from 220 to 238 g; and 43.1% in the group with fruit mass from 242 to 400 g.

Apparently, on average, during the ripening of fruits of medium-fruited cultivars and forms, the increase in juice mass occurred at a faster rate than the increase in the mass of the leathery pericarp and membranes.

Thus, selecting large pomegranates in order to obtain a greater quantity of juice per unit of raw material may be a mistake. On the contrary, in this case a significant portion of the juice may be lost compared

with the volume that could have been obtained by using medium-fruited pomegranate cultivars, in which only a few fruits reach a weight of 250 g.

This applies not only to large-fruited cultivars, but also to small-fruited cultivars with fruits weighing 200 g or less (less than 5 cm wide and 5.5 cm high), which are inferior in juice yield not only to medium-fruited cultivars but also to large-fruited cultivars and forms.

The results of this study can be used in early screening of breeding material. They also contain important information for pomegranate processors, who quite often obtain juice from a mixture of cultivars or select raw material for this purpose on the basis of taste and visual preferences alone.

In statistics, the coefficient of variation is often calculated as the ratio of the standard (root mean square) deviation of a random variable to its mathematical expectation. Its values reflect the degree of variability of the traits studied.

Table 6 presents the results of a targeted statistical processing of the data to establish whether a linear relationship exists between the masses of individual fruit components and juice yield.

Table 6
– Correlation between juice yield as a percentage of the total mass of a pomegranate fruit and the masses of its individual parts (P = 0.01; df = 25).

Pairs of traits	**r**		**r^2**
	Required	**Actual**	
Fruit mass (g) and juice yield (%)	0,51	-0,37	0,137
Mass of leathery pericarp (g) and juice yield (%)	0,51	-0,56	0,314
Mass of membranes (g) and juice yield (%)	0,51	-0,55	0,303
Mass of juicy arils (g) and juice yield (%)	0,51	0,02	0,0004
Mass of dehulled seeds (g) and juice yield (%)	0,51	-0,09	0,008
Juice mass (g) and juice yield (%)	0,51	0,34	0,116

The table shows that there is no complete linear relationship between such traits as juice mass and juice yield (r = 0.34 at a significance level of 0.99%). A close correlation between traits can be discussed only in cases where ($r \leq 0.7$).

At the same time, there is a significant (with a probability of 0.99) negative correlation between the mass of the leathery pericarp and juice yield, and between the mass of the membranes and juice yield: r = (− 0.56) and (− 0.55), respectively.

The obtained correlation coefficients between the mass of the leathery pericarp and juice yield (− 0.56), and between the mass of the membranes and juice yield (− 0.55), are moderate. They indicate that in

more than half of the cases, an increase in the mass of the peel and membranes leads to a decrease in juice yield.

A moderate correlation does not make it possible to speak of a causal relationship between these traits; therefore, the decrease in juice yield cannot be attributed with complete confidence to the mere fact of an increase in the mass of the leathery pericarp.

It is likely that the formation of peel mass (as well as membrane mass) and juice mass are two different processes that proceed at different rates. In some cases, juice formation may lag behind the formation of the peel and membranes, which is the reason for the negative correlation between the masses of the peel and membranes and juice yield.

Nevertheless, identifying a certain type of relationship between the mass of the leathery pericarp and juice yield, and between the mass of the membranes and juice yield, may be useful for understanding the relationship between these processes.

These results are to some extent consistent with those of a published study [17], which found that pomegranate fruit size, total peel mass and peel width, as well as the mass of 100 arils and juice mass, have a strong positive correlation ($p < 0.01$) with fruit mass.

However, the presence or absence of a relationship between juice yield as a percentage of total fruit mass and the mass of juice and solid parts was not examined in that study.

CONCLUSIONS

The carbohydrate complex of the 32 cultivar accessions is represented predominantly by invert sugar (12.35% on average), while the mass fraction of sucrose averaged 0.48%.

Unlike sugars, titratable acidity shows a fourfold decrease when moving from sour cultivars and forms (2.31%) to sweet cultivars (0.56%), which results in an increase in the SAI from 3.99 to 23.77.

The high genetic and biochemical diversity of the Goychay collection, confirmed by the coefficient of variation of the SAI (CV = 98.62%), makes it a valuable breeding resource. Cultivars can be purposefully selected from it for a wide range of objectives: from growing sweet dessert pomegranates for the fresh market to creating raw material for industrial processing.

The results of a separate experiment with 25 pomegranate cultivars and forms from the above-mentioned collection also showed that, although the mass of the fruit and its individual parts naturally increases during ripening, they can nevertheless be divided into three groups according to the dynamics of formation of the structural parts of the fruit:

1 – the rate of increase in the mass of the solid parts (peel and dehulled seeds) exceeds the rate of increase in juice mass;

2 – the mass of both the solid parts and the juice increases at almost the same rate;

3 – juice mass increases faster than the mass of the above-mentioned solid fruit parts, ultimately making it possible to grow more complete juice raw material with the maximum juice yield per unit of processed raw material.

Based on the statistical parameters studied in this work, it can be stated that the percentage of juice yield in medium-fruited cultivars (53.2 ± 5.3%) is higher than in large-fruited (43.1 ± 5.7%) and small-fruited (45.4 ± 7.0%) cultivars. This should be taken into account when selecting economically suitable raw material for pomegranate juice production and by breeders when developing new pomegranate cultivars.

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Unsectioned Paragraphs

Note: TSS – total soluble solids; SAI* – sugar-acid index.*

Note: Min–Max - variation limits (range of changes); $\bar{X}$ - arithmetic mean; SE -standard error of the mean; SD - root mean square (standard) deviation; CV - coefficient of variation.

Figures

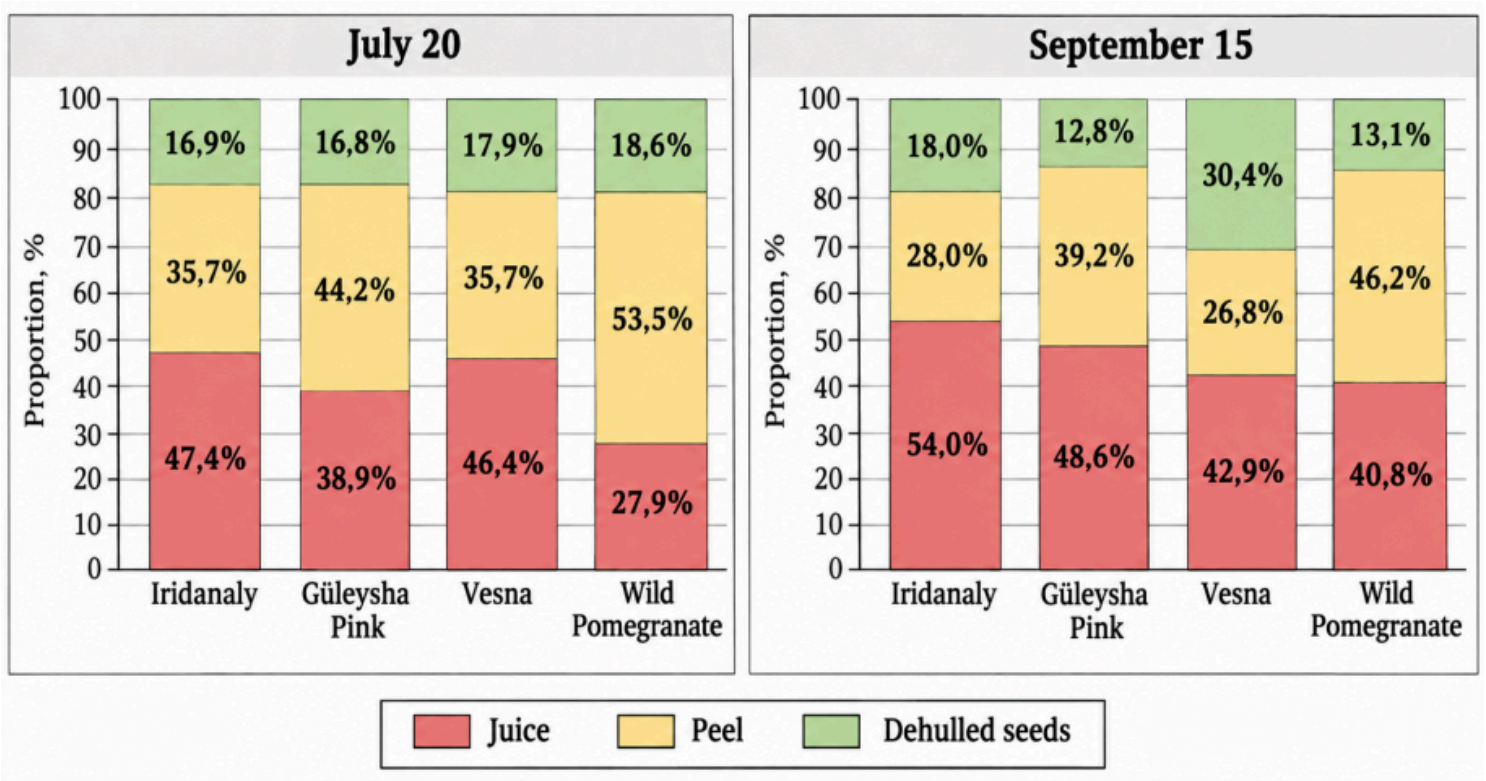

Figure 1

Percentage proportions of juice, peel, and dehulled seeds in the fruit of four pomegranate cultivar accessions.

Supplementary Files

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