Comparative analysis of the storage of pomegranate varieties under different conditions

Yashar Omarov[1], Ahad Nabiyev[1], Mehriban Aslanova[1], İlhama Kazimova[2], Elza Omarova[2], Afet Gasimova[1]

1 – Azerbaijan Technological University, Ganja, Azerbaijan
2 – Azerbaijan State University of Economics, Baku, Azerbaijan

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Corresponding author:

İlhama Kazimova
E-mail: kazimovailhama4655@gmail.com

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Abstract

Introduction. The objective of this study was to assess the impact of storage temperature, gas composition, and relative humidity on the quality of pomegranate varieties under long-term refrigerated storage conditions.

Materials and methods. The study examined local (Nazik Gabig, Iridane) and new (Gashang, Yeni Guleishe) pomegranate varieties. Phenolic compounds, including anthocyanins, were quantified using GC–MS. The enzymatic activities of ascorbate oxidase, polyphenol oxidase, peroxidase, and catalase were determined using spectrophotometric methods.

Results and discussion. Pomegranate varieties were stored in refrigerated chambers under four conditions: a controlled gas medium (CGM) with 3–4% CO_2 and 2–3% O_2 (variant I), CGM with 1–3% CO_2 and 2–3% O_2 (variant II), normal refrigeration (variant III), and CGM with 3–4% CO_2 and 2–3% O_2, a temperature of from −2 to −4 °C, and 92–95% relative humidity (variant IV). Storage durations were 6, 4, 3, and ≥7 months for variants I–IV, respectively. Natural and microbiological losses were monitored, and sensory evaluation was performed at the beginning, middle, and end of storage using a 10-point scale, considering taste, texture, color, and overall acceptability. Variant IV resulted in the lowest losses and highest sensory scores, demonstrating that the combination of controlled gas composition, low temperature, and high humidity is most effective in preserving fruit quality. These findings indicate that the Iridane and Yeni Guleyshe varieties are particularly suitable for long-term storage and commercial cultivation.

Analysis of anthocyanin composition revealed significant differences among varieties. High levels of delphinidin and cyanidin derivatives, especially in Yeni Güleyşe and Iridane, enhance their biological and functional value, contributing to strong antioxidant activity. Optimized storage conditions thus play a crucial role in maintaining both the sensory quality and health-promoting properties of pomegranate fruits.

Conclusions. Conventional refrigeration conditions led to a sharp decline in sensory properties. The fourth storage variant (temperature from −2 to −4°C, a controlled gas medium with 3–4% CO_2 and 2–3% O_2 under high relative humidity of 92–95% provided the highest sensory evaluation (9.2–9.7 points) and the lowest losses of the fruits (1.1–1.9%).

Introduction

The growing interest in healthy lifestyles and nutrient-rich foods has driven the development of new product lines in the food industry. Pomegranate (*Punica granatum* L.), a fruit native to South Asia and widely cultivated in tropical and subtropical regions, is prized for its high content of bioactive compounds, including phenolics, polyphenols, flavonoids, anthocyanins, essential minerals (such as potassium), and vitamins (C, A, and folic acid) (Giménez-Bastida et al., 2021; Noreen et al., 2025). Global pomegranate production currently reaches approximately 8.1 million tons, cultivated over a total area of 835,950 hectares, and continues to increase annually. Azerbaijan ranks among the leading pomegranate-producing countries worldwide, alongside India, Iran, Turkey, Egypt, the USA, Afghanistan, Tunisia, Spain, Peru, Pakistan, Italy, South Africa, and Mexico (Ezeora et al., 2024).

Regular, year-round consumption of pomegranate is recommended to maximize its health benefits, as its unique composition provides strong antioxidant and immunomodulatory effects, contributing to overall well-being. In addition, pomegranate and its derived products exhibit anticarcinogenic and anti-inflammatory activities (Akhundova et al., 2025; An et al., 2021; Zarfeshany et al., 2014), support cardiovascular health (Saeed et al., 2025), and daily intake has been associated with reductions in body mass index in healthy individuals (Stabnikova and Paredes-López, 2024). Pomegranate juice concentrate has demonstrated strong inhibitory effects against human pathogens such as *Streptococcus mutans* and *Aeromonas hydrophila* (Habib et al., 2023), while ellagitannins in pomegranate extract are converted in the intestines into urolithin A, which benefits the human gut microbiota and supports intestinal health (Bandow et al., 2025; Oseyko et al., 2019).

These multifaceted benefits underscore the potential of pomegranate both as a fresh fruit and in processed forms such as juice, extracts, and functional foods (Zhang et al., 2025).

Pomegranate has more than 500 cultivars distributed worldwide (Kandylis and Kokkinomagoulos, 2020). However, the type of cultivars that have prevailed in certain regions reflects the preferences and taste of the local populations. In general, the same basic pomegranate fruit is known by different names in different regions, and this is mainly because husk and aril color can markedly vary when grown in different regions. These differences mainly affect fruit size, husk color (ranging from yellow to purple, with pink and red most common), aril color (ranging from white to red), seed hardness, maturity, juice content, acidity, sweetness and astringency (Kandylis and Kokkinomagoulos, 2020). The composition of this fruit is characterized by its richness in individual representatives of phenolic compounds with natural antioxidant and antimicrobial properties, particularly flavonoids, biflavonoids, procyanidins, and other monomers, oligomers, and polymers (Suman and Bhatnagar, 2019).

Pomegranate has gained increasing global production and consumption in recent years because of its diverse applications and notable nutritional benefits. However, pomegranate is highly prone to weight loss and spoilage during postharvest handling and storage, which negatively affects consumer acceptability by reducing freshness, taste, and potential health-promoting compounds (Fawole and Opara, 2013). Therefore, establishing storage conditions that maintain fruit quality over extended periods is essential.

The present study aimed to evaluate the effects of different storage conditions - temperature, gas composition, and humidity - on the quality of pomegranate varieties during long-term refrigerated storage.

Materials and methods

Materials

The research objects included local pomegranate varieties widely cultivated in Azerbaijan, namely Nazik Gabig and Iridane, as well as newly developed varieties, Gashang and Yeni Guleyshe, grown at the Goychay Experimental Station of the Azerbaijan Research Institute of Horticulture and Subtropical Plants (Figure 1).

Figure 1. Studied pomegranate varieties

Nazik Gabig. Widely cultivated in the Ganja–Gazakh region, the fruits are flattened-round, bright red, with a thin peel, and weigh 200–250 g on average. Harvesting occurs in the second half of October.

Iridane. A local variety grown in Shirvan, Absheron, and Ganja, with round or elongated fruits weighing 220–250 g on average (up to 350–550 g). The thin-skinned fruits have large arils (100 arils weigh 36.5–39 g, occasionally up to 45 g) and high juice yield (52–54%). Both fruit and juice are dark cherry-colored, with 14.4% sugar and 1.84% titratable acidity. Storage ability is moderate, transport tolerance low; mainly used for juice and as a dessert fruit.

Gashang. Cultivated in Shirvan, this medium-height tree has drooping branches and few thorns. Fruits are large (400–500 g), with thick, bright dark crimson peel, thick internal partitions, and large, red arils arranged regularly, with a sweet-sour taste.

Yeni Guleyshe. Grown in Shirvan, Karabakh, and Ganja, the tree has a rounded crown with dense, upright branches. Fruits are globular with a cylindrical neck, thin glossy peel, large dark cherry arils, and small thin seeds. Average fruit weight is 220 g, with sweet–sour taste, sugar content 15.95% and acidity 1.84%. The thin internal partitions yield bright red, high-quality juice, and the fruits are widely consumed locally.

Storage conditions

The pomegranate fruits were pre-sorted, individually cleaned of foreign impurities, and placed in storage containers with a capacity of 8–10 kg before being stored in refrigerated chambers. During the study, the pomegranate fruits were stored in refrigerated chambers under four different conditions.

Pomegranate fruits were stored in refrigerated chambers under four conditions: a controlled gas medium (CGM) with 3–4% CO_2 and 2–3% O_2 (variant I), CGM with 1–3% CO_2 and 2–3% O_2 (variant II), normal refrigeration (variant III), and CGM with 3–4% CO_2, 2–3% O_2, a temperature of −2 to −4 °C, and 92–95% relative humidity (variant IV) (Table 1).

Table 1

Storage conditions of pomegranate fruits

Storage variant	Storage conditions	Atmosphere conditions	Chamber temperature, °C	Relative humidity, %	Internal fruit temperature, °C
I	Refrigeration chamber with controlled atmosphere	3–4% CO_2 and 2–3% O_2	from 0 to +3	80–90	from +3 to +5
II	Refrigeration chamber with controlled atmosphere	1–3% CO_2 and 2–3% O_2	from 0 to +3	80–90	from +3 to +6
III	Refrigerated chamber under standard conditions	—	from 0 to +3	80–90	from +3 to +6
IV	Refrigeration chamber with controlled atmosphere at low temperature	3–4% CO_2 and 2–3% O_2	from –2 to –4	92–95	from 0 to +1

Storage durations were 6, 4, 3, and ≥7 months for variants I, II,II, and IV, respectively.

Methods

The quality parameters of pomegranate varieties were examined across all variants once a month until the end of storage.

Chemical composition of pomegranate fruits. Besides, the changes in key quality indicators, such as total sugars, titratable acidity, phenolic compounds, and vitamin C, were determined (Hasil, 2004).

Determination of phenolic compounds. Using the modern analytical method of Gas Chromatography–Mass Spectrometry (Flamini and Traldi, 2010), the individual representatives of phenolic compounds, including anthocyanins, were quantified in the local Nazik Gabig and new Yeni Guleyshe pomegranate varieties.

Determination of ezymatic activity. During the storage of pomegranate fruits under different conditions, the changes in the activity of enzymes belonging to the oxidoreductase class (ascorbate oxidase, polyphenol oxidase, peroxidase, and catalase) were studied (Hasil, 2004; Nabiyev et al., 2008).

During the storage of pomegranate varieties both natural and microbiological losses were also identified. The degustation of each variety was also carried out separately at the beginning, middle, and end of the storage period (Cefola and Pace, 2016).

Statistical analysis

All experiments were performed in triplicate. The results are expressed as mean ±standard deviation. Statistical analyses were conducted using appropriate software and Microsoft Excel.

Results and discussion

During storage of pomegranate varieties under the first three conditions (variants I–III) in refrigerated chambers, the chamber temperature was maintained at 0 to +3 °C, with relative humidity of 80–90%. Owing to the relatively thick peel of pomegranate fruits, the internal temperature of the fruits in variants I–III remained above 0 °C, which is an important factor for quality preservation. During long-term storage, the internal fruit temperature was regularly monitored at 10-day intervals using a Pocket Test Thermometer.

The results showed that the internal temperature of the fruits ranged from +3 to +4 °C and, in some cases, reached +5 to +6 °C. Such conditions may intensify respiration and fermentation processes, leading to increased nutrient losses. Therefore, the implementation of the fourth storage variant was required to ensure more effective preservation. The primary objective of variant IV was to reduce fermentation activity and limit nutrient depletion associated with respiration. Under this storage condition, the internal temperature of the pomegranate fruits was maintained at 0 to ±1 °C, indicating more favorable storage conditions. Prior to storage under the different variants, the activities of oxidoreductase enzymes, including ascorbate oxidase, polyphenol oxidase, peroxidase, and catalase, were evaluated, as these enzymes play a key role in oxidative processes during fruit storage (Table 2).

Table 2

Enzyme activity (µg/mol) of pomegranate fruits before storage

Storage variant	Enzyme	Local pomegranate varieties		New pomegranate varieties	
		Nazik Gabig	Iridane	Gashang	Yeni Guleyshe
I	Ascorbate oxidase	0.66±0.03	0.55±0.02	0.80±0.04	0.88±0.04
II	Polyphenol oxidase	0.74±0.03	0.72±0.03	0.78±0.03	0.74±0.03
III	Peroxidase	2.10±0.08	1.98±0.07	1.32±0.05	2.21±0.09
IV	Catalase	0.44±0.02	0.36±0.02	0.34±0.02	0.30±0.01

Enzymes are organic compounds present in all living organisms and play a crucial role in sustaining life. Fundamental biological processes—including photosynthesis, respiration, nutrient absorption, and the synthesis and transformation of proteins, lipids, and carbohydrates—occur with the participation of enzymes (Patel et al., 2016). During the storage and processing of pomegranate fruits and other food products, complex biochemical reactions take place, the regulation of which largely depends on enzymatic activity. Therefore, the objective of this study was to investigate enzyme activity and the dynamics of its changes during storage.

One of the key enzymes involved in pomegranate fruit maturation and the enhancement of nutritional value is ascorbate oxidase, an aerobic dehydrogenase belonging to the oxidoreductase class. This metalloprotein catalyzes the oxidation of ascorbic acid to dehydro-L-ascorbic acid. In the storage and processing of plant-based products, including pomegranate fruits, it is essential to establish conditions that reduce or completely inhibit the activity of this enzyme. Otherwise, increased ascorbate oxidase activity leads to a decrease in vitamin C content and accelerates its utilization during respiration (Aslanova et al., 2014).

Polyphenol oxidase has been relatively less studied in pomegranate compared to other fruits and berries. Chemically, polyphenol oxidase is a coenzyme and contains copper as an active group. This enzyme catalyzes a wide range of polyphenols, facilitating the conversion of ortho- and para-diphenols into ortho-quinones.

Catalase breaks down hydrogen peroxide, which forms during the tissue respiration process in fruits and vegetables, including pomegranates, into water and molecular oxygen. Through this catalytic activity, living cells, including human cells, are protected from the harmful effects of hydrogen peroxide.

The primary objective of studying enzyme activity is to regulate metabolic processes that may occur during the long-term storage of pomegranate varieties under different conditions in refrigerated chambers. It is well known that plant-based products, including pomegranates, should be stored under conditions that prevent changes in enzyme activity, keeping them stable or in a permanently inactivated (inhibited) state. An increase in enzyme activity facilitates the consumption of key quality components of pomegranate varieties in the respiration process. To ensure the long-term preservation of food products, including pomegranate varieties, with maintained quality, enzyme activity must be continuously monitored throughout the storage period (Kazimova and Nabiyev, 2022).

Besides, before storage, the main quality indicators of pomegranate varieties, including soluble dry matter, total sugars, titratable acidity, phenolic compounds, and vitamin C, were examined. A review of the literature revealed that pomegranate juice contains more than 400 organic and inorganic compounds (Hasil, 2004). The dry matter of pomegranate juice mainly consists of simple sugars, which are representatives of carbohydrates. It is well known that sugars are the products of the photosynthesis process. During photosynthesis, not only carbohydrates but also other essential organic and inorganic compounds necessary for life are synthesized. Even oxygen, which is crucial for the survival of all living organisms, is a product of photosynthesis. As a result of the proper functioning of this process, plant-based food products, including pomegranates, can possess high nutritional value.

In modern times, ecosystem disruption, drought, climate change, and stress factors affect the proper progression of the photosynthesis process. As a result, these factors can negatively impact the quality of food products, including fruits and berries. Therefore, it is crucial for people to strive for ecosystem conservation. As mentioned earlier, the dry matter of pomegranate mainly consists of simple sugars. Among these, glucose and fructose are the most abundant (approximately 50%). As pomegranate fruit ripens, the amount of simple sugars in its composition gradually increases. According to literature sources and the results of our research, unripe pomegranate varieties contain lower amounts of glucose and fructose compared to ripe fruits. Therefore, only fully ripened pomegranates should be used for both fresh consumption and long-term storage. Additionally, pomegranate juice contains other sugars such as pentoses, sucrose, pectin substances, and various other compounds.

The main quality indicator of pomegranate varieties is their richness in organic acids. In the composition of pomegranate fruit, organic acids are found in high amounts in the juice, while they are present in smaller quantities in the peel, membranes, and seeds. Pomegranates contain aliphatic polybasic organic acids. These acids are also referred to as natural, non-volatile, and titratable acids. The total acidity of fully ripened pomegranates ranges from 2% to 7%, depending on the variety. In wild pomegranate varieties, total acidity is higher, reaching 5%–12%. In fully ripened pomegranates, citric acid constitutes approximately 75%–80% of the total acidity, while oxalic acid and other acids make up 10%–15%. As noted in the literature, citric acid, along with oxalic acid, contributes to blood purification, blood pressure regulation, and the normalization of blood pressure and cholesterol levels in the body.

The main physicochemical and biochemical parameters of fully ripened pomegranate varieties before storage are presented in Table 3.

Table 3

Physicochemical and biochemical parameters (%) of pomegranate fruits before storage

Parameter	Local pomegranate varieties		New pomegranate varieties	
	Nazik Gabig	Iridane	Gashang	Yeni Guleyshe
Total dissolved solids	17.2±0.2	17.4±0.2	17.6±0.3	17.4±0.2
Total sugar	13.6±0.3	14.4±0.4	15.4±0.5	15.2±0.4
Titrable acidity	2.3±0.05	1.50±0.04	1.66±0.05	1.94±0.06
Phenolic compounds	1.3±0.06	1.3±0.05	1.02±0.04	0.92±0.03
Vitamin C	16.6±0.7	22.1±0.9	17.6±0.8	20.2±0.9

Note: The amount of vitamin C is expressed in mg%.

The total acidity in the studied pomegranate varieties ranged between 2.3% and 1.94% (Table 3). The data also show that the Gashang variety differs from the others in terms of total dissolved solids (17.6%) and total sugar content (15.4%). The highest titratable acidity was observed in the Nazik Gabig variety (2.3%), while the highest levels of phenolic compounds were found in the Nazik Gabig and Iridane varieties (1.3%). Vitamin C content was highest in the Iridane (22.1 mg/%) and Yeni Guleyshe (20.2 mg/%) varieties, distinguishing them from the others.

Pomegranate varieties are rich in water-soluble vitamin C, a biologically active compound essential for metabolic processes, protein and enzyme synthesis. Vitamin C deficiency can lead to colds, fatigue, loss of appetite, and disrupted lipid metabolism, increasing blood cholesterol. As shown in Table 3, the analyzed pomegranate varieties contain high levels of vitamin C, supporting their inclusion in the daily diet for maintaining health.

Total phenolic compounds are important quality indicators in pomegranate varieties. These biologically active substances exhibit strong antioxidant, antimicrobial, antiviral, and antimutagenic effects, support blood circulation, enhance memory, and reduce fatigue. Anthocyanins and their glycosides also aid in eliminating radiation, making pomegranate juice and red wine beneficial for exposed individuals.

The study examined enzyme activity and quality indicators of different pomegranate varieties during storage under various conditions (Table 4).

Table 4

Enzyme activity (%) of pomegranate fruits during storage under different conditions

Enzyme	CGM with 3-4% CO_2 and 2-3% O_2	CGM with 1-3% CO_2 and 2-3% O_2	In refrigerated chamber	CGM with 3-4% CO_2 and 2-3% O_2, -2 to -4 °C
Nazik Gabig				
Ascorbate oxidase	81.1±2.4	62.2±2.1	39.2±1.8	96.0±1.2
Polyphenol oxidase	84.1±2.6	63.6±2.3	40.9±1.9	100.0±0.0
Peroxidase	80.0±2.5	68.6±2.4	14.3±1.1	100.0±0.0
Catalase	70.4±2.3	63.6±2.2	13.6±1.0	95.5±1.3
Iridane				
Ascorbate oxidase	69.0±2.2	57.5±2.0	20.0±1.3	94.0±1.4
Polyphenol oxidase	75.6±2.4	55.5±2.1	33.3±1.6	100.0±0.0
Peroxidase	78.8±2.5	64.6±2.3	18.2±1.2	98.0±1.1
Catalase	72.2±2.3	61.1±2.2	22.0±1.4	95.0±1.3
Gashang				
Ascorbate oxidase	77.5±2.4	72.5±2.3	31.2±1.6	94.5±1.4
Polyphenol oxidase	85.7±2.7	71.4±2.4	45.7±1.9	100.0±0.0
Peroxidase	78.8±2.5	69.4±2.4	25.0±1.5	100.0±0.0
Catalase	72.2±2.3	66.7±2.2	22.0±1.4	98.0±1.1
Yeni Guleyshe				
Ascorbate oxidase	79.5±2.5	63.6±2.2	31.8±1.6	93.4±1.4
Polyphenol oxidase	80.5±2.6	63.9±2.3	38.9±1.8	96.5±1.2
Peroxidase	80.0±2.5	68.6±2.4	14.3±1.1	100.0±0.0
Catalase	75.0±2.4	70.4±2.3	13.6±1.0	100.0±0.0

Table 4 shows that during long-term refrigerated storage, enzyme activity remained partially active under variants I–III. Under variant III (normal refrigeration), peroxidase and catalase activity sometimes exceeded initial levels. In local varieties, peroxidase decreased by 78.8–80% in variant I, 64.6–69.4% in variant II, and 14.3–25% in variant III, with similar trends for catalase. Ascorbate oxidase and polyphenol oxidase activity decreased most under variant I, indicating higher nutrient consumption in variants II and III. In contrast, variant IV nearly completely inhibited enzyme activity: peroxidase and polyphenol oxidase by 100%, ascorbate oxidase by 96%, and catalase by 95.5%.

Comparison of variants shows that the higher CO_2 concentration in variant I had a stronger inhibitory effect on enzyme activity. During long-term storage under variants I–III, enzymes were not fully inactivated, and in some cases, activity even increased. Internal fruit temperatures ranged from +3 to +4 °C, occasionally reaching +5 °C, due in part to the thicker pomegranate skin. In the variant IV (3–4% CO_2, 2–3% O_2, from −2 to −4°C, with internal fruit temperature maintained at 0±1°C), enzyme activity was effectively suppressed. In the local variety Nazik Gabig, ascorbate oxidase activity decreased by 96%, polyphenol oxidase and peroxidase were completely inactivated, and catalase activity decreased by 95.5%. In the variety Gashang, activity of ascorbate oxidase decreased by 94.5%, polyphenol oxidase and peroxidase were fully inactivated, and catalase decreased by 98% (Table 4). At the end of storage under variant IV, the pomegranate varieties almost completely retained their external appearance, allowing storage not only for 5–6 months but up to 8 months.

The main physicochemical and biochemical parameters of pomegranate varieties during storage under different conditions have also been studied (Table 5).

Table 5 indicates that conditions in variant IV best preserved dry matter and total sugars in both local and new pomegranate varieties, while variant III showed the greatest losses, with variants I and II showing intermediate reductions.

Figure 1 shows that variant IV experienced the smallest decrease in antioxidant phenolic compounds and vitamin C compared to the other variants. This is largely due to stronger inhibition of polyphenol oxidase and ascorbate oxidase, which catalyze these compounds. Reduced enzyme activity in plant-based products, including pomegranate, slows nutrient degradation during storage. The results indicate that limiting enzyme activity in refrigerated pomegranate significantly reduces respiration, and maintaining a gas composition of 3–4% CO_2 and 2–3% O_2, and a temperature of −2 to −4°C best preserves fruit quality.

Before storage, the anthocyanin content of fully mature pomegranate varieties were determined using chromatography–mass spectrometry, with the results presented in Table 6.

Anthocyanins are water-soluble flavonoid pigments responsible for the characteristic color of pomegranate juice and represent the most widely distributed flavonoids in this fruit. Their aglycone forms, known as anthocyanidins, include six major compounds commonly found in fruits: cyanidin, delphinidin, pelargonidin, peonidin, petunidin, and malvidin (Stabnikov et al., 2025). Unlike catechins, anthocyanins readily form glucosides by binding with sugars and organic acids, which enhances product stability during storage. At concentrations of 300 mg/L or higher, anthocyanins significantly suppress oxidative enzyme activity and inhibit certain pathogenic microorganisms. Biologically, anthocyanins contribute to cholesterol regulation, cerebral vasodilation, memory improvement, and the removal of radionuclides from the body, supporting the health value of pomegranate products (Bagirzade et al., 2024; Nabiyev and Moslemzadeh, 2008).

Anthocyanin profiling by GC–MS (Table 6) showed marked cultivar-dependent differences. Delphinidin-3-O-glucoside ranged from 15.54 mg/L in Nazik Gabig to 19.48 mg/L in Iridane, while cyanidin derivatives (cyanidin-3-O-glucoside and cyanidin-3,5-O-diglucoside) were the predominant anthocyanins in all cultivars, reaching the highest levels in Iridane and Yeni Guleyshe. In contrast, cyanidin-3-O-rutinoside and pelargonidin-3-O-glucoside were present in the lowest amounts. Overall, Yeni Guleyshe and Iridane exhibited higher total anthocyanin contents than Nazik Gabig and Gashang, enhancing their biological and functional value. These results highlight the importance of optimized cold-storage conditions to preserve anthocyanins during long-term storage.

Table 5

Physicochemical and biochemical parameters (%) of pomegranate fruits during storage under different conditions

Parameter	CGM with 3-4% CO_2 and 2-3% O_2	CGM with 1-3% CO_2 and 2-3% O_2	In refrigerated chamber	CGM with 3-4% CO_2 and 2-3% O_2, -2 to -4 °C
Nazik Gabig				
Total dissolved solids	5.2±0.3	7.0±0.4	12.9±0.6	3.8±0.2
Total sugar	5.1±0.3	7.3±0.4	14.7±0.7	2.6±0.2
Titrable acidity	8.7±0.4	21.0±0.8	30.4±1.1	5.6±0.3
Phenolic compounds	6.9±0.4	10±0.5	16.9±0.7	3.8±0.2
Vitamin C	18.2±0.9	22.7±1.0	40.9±1.4	11.8±0.6
Iridane				
Total dissolved solids	5.7±0.3	8.0±0.4	11.5±0.6	3.2±0.2
Total sugar	5.5±0.3	7.6±0.4	12.5±0.6	1.8±0.1
Titrable acidity	8.7±0.4	10.0±0.5	13.3±0.6	4.8±0.3
Phenolic compounds	7.7±0.4	11.4±0.5	20.8±0.8	4.0±0.2
Vitamin C	21±1.0	27.6±1.1	31.6±1.2	8.5±0.4
Gashang				
Total dissolved solids	4.5±0.3	6.7±0.4	11.9±0.6	3.4±0.2
Total sugar	6.5±0.4	8.4±0.5	13±0.6	3.2±0.2
Titrable acidity	7.8±0.4	10.6±0.5	18.2±0.7	4.4±0.3
Phenolic compounds	8.8±0.4	10.8±0.5	20±0.8	4.9±0.3
Vitamin C	17.1±0.8	19.5±0.9	34.1±1.3	11.2±0.6
Yeni Guleyshe				
Total dissolved solids	5.7±0.3	6.9±0.4	11.5±0.6	2.8±0.2
Total sugar	5.9±0.3	7.2±0.4	13.8±0.6	2.8±0.2
Titrable acidity	9.2±0.4	10.8±0.5	17.5±0.7	4.1±0.3
Phenolic compounds	7.6±0.4	11.9±0.5	23.9±0.9	4.3±0.2
Vitamin C	15.8±0.8	22.4±1.0	40.8±1.4	6.4±0.4

Note: The amount of vitamin C is expressed in mg%

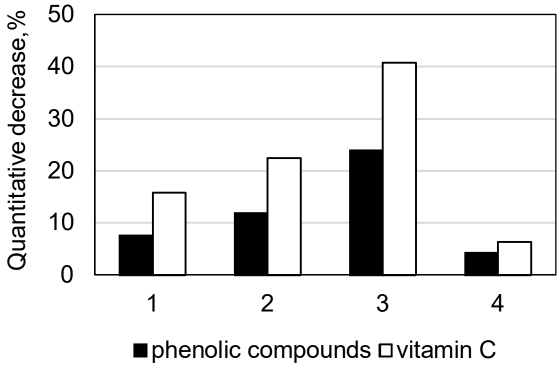

Figure 1. Reduction (%) in the content of phenolic compounds and vitamin C in the *Yeni Guleyshe* pomegranate variety during storage under different conditions

Table 6

Content of anthocyanin (mg/l) in fully ripe pomegranate fruits before storage

Anthocyanins	Nazik Gabig	Iridane	Gashang	Yeni Guleyshe
Delphinidin-3-O-glucoside	15.5365	19.4803	17.4275	18.4803
Delphinidin-3,5-O-diglucoside	6.7350	8.8863	7.6260	9.7833
Cyanidin-3-O-rutinoside	0.4183	0.7560	0.5253	0.8660
Cyanidin-3-O-glucoside	30.4870	37.6190	31.5726	35.5090
Cyanidin-3,5-O-diglucoside	36.6453	41.3137	38.5863	39.4137
Pelargonidin-3-O-glucoside	3.1259	3.5816	3.2019	4.0819
Unidentified	0.8870	1.072	0.9080	1.1722

The study also aimed to investigate the loss rates during the storage of pomegranate varieties under different conditions. It is known that during the long-term storage of fruits and vegetables, including pomegranate fruits, both natural and microbiological losses occur. During the storage period, the conditions in the refrigerated chamber should be optimized to minimize natural and microbiological losses. The storage of pomegranate varieties in the refrigerated chamber was carried out for 6 months under variant I, 4 months under variant II, 3 months under variant III, and for 7 months or more (until the end of May) under variant IV. Natural and microbiological losses during the storage of pomegranate varieties under different variants have been determined.

Detailed data on natural, microbiological, and total losses for each storage variant and cultivar are presented in Table 7. In local varieties, Nazik Gabig and Iridane showed the lowest losses in variant I (2.8% and 2.4%), increasing to ~5% in variant II and ~10% in variant III. Similar trends were observed in the new varieties, Gashang and Yeni Guleyshe, with losses of 3.1% and 2.7% in variant I, 5.4% and 4.8% in variant II, and 11.6% and 10.2% in variant III. Across all cultivars, variant IV had the lowest natural and microbiological losses, demonstrating its superior effectiveness for long-term storage.

Sensory evaluation was performed to assess the quality of pomegranate varieties during storage under different conditions, using a 10-point scale (Table 8).

Table 7

Loss rates (%) during the storage of pomegranate fruits under different conditions

Pomegranate varieties	Variant I Storage for 6 months			Variant II Storage for 4 months			Variant III Storage for 3 months			Variant IV Storage for 7 months		
	NL	ML	TL	NL	ML	TL	NL	ML	TL	NL	ML	TL
Nazik Gabig	1.9	0.9	2.8	3.1	2.1	5.2	6.3	4.2	10.4	1.2	0.6	1.8
Iridane	1.7	0.7	2.4	3.0	2.0	5.0	6.2	4.6	10.6	1.6	0	1.6
Gashang	1.9	1.2	3.1	3.2	2.2	5.4	6.8	4.8	11.6	1.2	0.7	1.9
Yeni Guleyshe	2.0	0.7	2.7	2.4	2.4	4.8	6.6	3.6	10.2	1.1	0	1.1

Note: NL, natural loss; ML, microbiological loss; TL, total loss.

Table 8

Tasting score (points) of pomegranate fruits after storage under different conditions

Pomegranate varieties	Variant I	Variant II	Variant III	Variant IV
	6 months	4 months	3 months	7 months
Nazik Gabig	8.8	8.4	7.6	9.4
Iridane	8.6	7.6	7.0	9.6
Gashang	8.5	8.0	7.1	9.2
Yeni Guleyshe	**9.0**	**8.6**	**8.0**	**9.7**

Sensory evaluation yielded scores of 8.5–9.0 in variant I, 7.6–8.6 in variant II, 7.0–8.0 in variant III, and the highest values, 9.2–9.7, in variant IV. After long-term storage, Iridane and Yeni Guleyshe achieved the top scores of 9.6 and 9.7, respectively. Overall, storage under variant IV (3–4% CO_2, 2–3% O_2, −2 to −4 °C, 92–95% relative humidity) maintained superior sensory quality and minimized natural losses compared with other variants.

Conclusions

The study demonstrated that storage conditions significantly affect the preservation of pomegranate fruit quality. Under conventional refrigeration, all studied local and newly developed cultivars showed pronounced reductions in soluble solids, total sugars, titratable acidity, phenolic compounds, vitamin C, and sensory attributes. In contrast, storage under a controlled atmosphere with reduced temperature (from –2 to –4 °C) and an optimized gas composition (3–4% CO_2 and 2–3% O_2) proved to be the most effective approach, ensuring minimal losses of key quality parameters and slowing physiological and biochemical processes in the fruits. Storage under variant IV resulted in the highest sensory scores (9.2–9.7 points) and the lowest total losses (1.1–1.9%). The results also revealed significant cultivar-dependent differences in anthocyanin composition and content. In particular, the elevated levels of delphinidin and cyanidin derivatives in the Yeni Guleyshe and Iridane cultivars enhanced their biological and functional value. Given the important role of anthocyanins in human health, the application of optimal refrigeration regimes during long-term storage is essential to minimize the depletion of these biologically active compounds through respiratory processes and to preserve the nutritional quality of pomegranate fruits.

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