International Journal of Design & Nature and Ecodynamics
Vol. 20, No. 12, December, 2025, pp. 2897-2907
Journal homepage: http://iieta.org/journals/ijdne

Valorization of Winery By-Products: Comprehensive Profiling of Bioactive Compounds in Peels of Three Azerbaijani Pomegranate (*Punica granatum* L.) Cultivars

Umide Majnunlu[1,2*], Vugar Mikayilov[3], Vugar Salimov[4], Guven Ozdemir[5]

[1] Department of Engineering and Applied Sciences, Azerbaijan State University of Economics (UNEC), Baku AZ1001, Azerbaijan
[2] Department of Physical and Chemical Analyses, Research Institute of Viticulture and Winemaking, Baku AZ0118, Azerbaijan
[3] Department of Chemical Technology, Azerbaijan State Oil and Industry University, Baku AZ1010, Azerbaijan
[4] Director of Research Institute of Viticulture and Winemaking, Ministry of Agriculture of the Republic of Azerbaijan, Baku AZ0118, Azerbaijan
[5] Department of Biology, Faculty of Science, Ege University, İzmir 35040, Türkiye

Corresponding Author Email: umidamacnunlu@gmail.com

https://doi.org/10.18280/ijdne.201214

Received: 15 November 2025
Revised: 17 December 2025
Accepted: 25 December 2025
Available online: 31 December 2025

Keywords:
fatty acid profile, minerals, pomegranate peel, proximate composition, vitamins

ABSTRACT

The aim of this study is to scientifically evaluate the bioactive composition of peel samples of Bala Mursal, Azerbaijan Guloyshe, and Nazik Gabig pomegranate varieties generated during processing, with particular emphasis on vitamins, minerals, and fatty acids, in order to assess their potential use as promising raw materials for functional food additives and high-value biotechnological products. This investigation is conducted to obtain bioactive compounds from the peels of the Bala Mursal (Aghsu), Azerbaijan Guloyshe (Aghsu), and Nazik Gabig (Goychay) pomegranate varieties obtained during processing from winemaking factories located in the Aghsu and Goychay districts of the Nagorno Shirvan economic region, and to study their health benefits for the purpose of food supplement applications. Peel samples were collected in October from processing facilities in the Aghsu and Goychay districts at full commercial maturity to minimize seasonal variability. Pomegranate peels contain many bioactive compounds such as vitamins, fatty acids, and mineral elements. The antioxidant properties of these compounds further contribute to their functions, such as protection against oxidative stress and reducing the risk of chronic diseases, including anti-cancer, antibacterial, and cardiovascular protection. For this purpose, the chemical and nutritional composition of the research samples was analyzed using modern equipment in accordance with the appropriate methodology. All compositional analyses were conducted on a dry-weight basis. When determining the fatty acid profile, minerals, proximate composition, and vitamins, it was revealed that the moisture level varied in the range of 7% (Nazik Gabig) – 9% (Azerbaijan Guloyshe). The crude fiber amount varied from 18.89% in Bala Mursal 18.93% in Azerbaijan Guloyshe. The crude ash content ranged from 3.74% in Azerbaijan Guloyshe to 3.77% in Nazik Gabıg, while the crude protein content varied from 2.96% in Nazik Gabıg to 2.99% in Bala Mursal. The crude fat content ranged from 1.34% in Bala Mursal to 1.38% in Azerbaijan Guloyshe. The vitamin A content showed a wider variation, ranging from 0.176 mg/100 g in Bala Mursal to 13.26 mg/100 g in Azerbaijan Guloyshe. The results on mineral content were wider, with iron in Bala Mursal being 5 mg/100 g and potassium in Azerbaijan Guloyshe being 338 mg/100 g. 19 fatty acids were found in pomegranate peels, with the highest fatty acid amount being oleic acid, which was found in Azerbaijan Guloyshe - 20.98883%. The least fatty acids were pentadecanoic, myristic, palmitoleic, arachidic, gamma-linolenic, behenic, docosadienoic, lignoceric, eicosapentaenoic, nervonic, and docosahexaenoic, varying in the range of 0.31912-2.98725%.

1. INTRODUCTION

The increasing volume of by-products generated in the food processing industry and the inefficient management of these resources remain a serious problem in terms of global food security and environmental sustainability [1, 2]. In particular, the fruit and vegetable processing sector is one of the largest producers of organic by-products, accounting for approximately 45% of total food waste, and the pomegranate processing industry occupies a special place in this category [3, 4]. The separation of a large part of the peel and seeds as waste during pomegranate processing causes a significant loss of bioresources on an industrial scale [5]. However, various studies show that pomegranate peel is rich in high-value

bioactive components, including fatty acid profile, proximate composition, vitamins, and minerals [6-8]. The antioxidant, anti-inflammatory, antimicrobial, metabolic health-supporting, and potential anti-cancer effects of these components provide a scientific basis for their use as functional ingredients [9-12].

In addition, literature reviews show that the chemical composition and bioactive profile of pomegranate peel vary with variety, growing area, soil conditions, and agroecological factors [13]. The existence of more than 500 pomegranate varieties in the world, and more than 60 in Azerbaijan, indicates this diversity. However, scientific sources have mainly studied the peels of commercial varieties from other countries, and systematic and comparative chemical-proximate profile data on Azerbaijani varieties have been almost completely absent. This gap creates a fundamental lack of information for evaluating local varieties as high-value bioresources rather than industrial waste. It also limits the scientific justification of the use of local raw materials as functional nutrients, natural antioxidant sources, and food additives. This study hypothesizes that peels from locally important Azerbaijani cultivars possess a distinct and rich profile of nutrients and bioactive compounds, making them suitable for valorization as functional food ingredients.

2. MATERIALS AND METHODS

In the initial stage, the pomegranate peels (a rich source of natural compounds), which were the object of our research, were washed and cleaned, then cut into small pieces and dried in a drying device in 2 stages at a specified temperature and moisture. The moisture amount of pomegranate peels varied by variety, and was 61% in Azerbaijan Guloyshe, 60% in Bala Mursal, and 59% in Nazik Gabig. Thus, in the first stage, the pomegranate peels, which we used in the research with 4400 grams for each variety, were cleaned and placed in a drying device for 50 minutes at a temperature of 60 degrees, depending on the variety, until they reached 14-16% moisture content. The first stage of the drying process was completed with a mass of 2624-2620 g for each variety and a moisture amount of 35-37%. In the second stage of the process, the shells with a mass of 2624-2620 g were placed in a drying device for 2 hours at 55 degrees Celsius for each variety until the moisture amount reached 7-9%. After the drying process was completed, the mass of pomegranate peels was determined by variety, in the range of 1.026 - 1.019 g, and the moisture amount was determined as 9% for Azerbaijan Guloyshe, 7% for Nazik Gabig, and 8% for Bala Mursal. Then, the pomegranate peels were ground. After the process was completed, the moisture index of the pomegranate peel powder was determined by a moisture analyzer.

2.1 The determination of crude oil

First, extraction pouches were prepared. Filter paper measuring 110 × 90 mm was used to prepare the pouches. The filter paper was made in the form of a pouch, then was kept in a Soxhlet in ether for 1 hour, and then was put into a weighing bottle. The weighing bottle lid was dried in an oven at 105°C for 1 hour, then was placed in a desiccator, cooled, and weighed on an analytical balance with an accuracy of ± 0.001 grams (m_1). 1.0 gram of sample was dried and placed into the weighed pouch on an analytical balance to an accuracy of ± 0.001 grams, the mouth of the pouch was closed, the pouch was placed into the used weighing bootle during drying and kept in a drying oven at 105°C for 3 hours, then was cooled in a desiccator and weighed on an analytical balance to an accuracy of ± 0.001 grams (m_2). The weighed pouch was placed into the extractor of the Soxhlet apparatus vertically. The feed particles were extracted with diethyl ether. The appropriate amount for the feed type was poured into the flask of the Soxhlet apparatus. At this time, ether is poured into the flask of the Soxhlet apparatus in such an amount that the total volume of solvent after draining from the extractor does not exceed 2/3 of the volume of the flask. The sample was kept in the apparatus with ether overnight, and extraction was continued the next day. The next day, extraction was carried out in a Soxhlet apparatus for 5–8 hours. At the end of the extraction, the pouches were removed from the Soxhlet apparatus, and the ether was allowed to evaporate completely. Then the pouch was placed into the same weighing bottle and was dried in a drying oven at 105°C for 1 hour, cooled in a desiccator, and weighed on a balance. It was dried again for 30 minutes and weighed on the analytical balance; this process was continued until the difference between two consecutive masses was less than 0.001 grams (If the mass increases during the drying process, the minimum mass is taken as the final result (m_3)).

The mass fraction of crude oil in dry matter, X_1 (%), is calculated by the following formula:

$$X_1 = \frac{m_2 - m_3}{m_2 - m_1} \times 100$$

where,

m_2 – weight of the pouch and the weighing bottle with the sample before extraction, g

m_3 – weight of the pouch and the weighing bottle with the sample after extraction, g

m_1 – weight of the dried pouch and weighing bottle, g

The mass fraction of crude oil in the sample (X_2, %) is calculated by the following formula:

$$X_2 = \frac{X_1 \times (100 - W)}{100}$$

where,

X_1 — mass fraction of crude oil in dry mass,

W – mass fraction of moisture obtained according to the internal instruction (T-BP-056).

2.2 The determination of crude ash

In the analysis process, the sample was weighed with an accuracy of 5 ± 0.001 g and was placed into a crucible. The sample was heated in a heater until it was carbonized. The sample was kept in a preheated muffle furnace (at least 30 minutes) at 550 ± 25°C for 3.0 hours. After the ashing was completed, the sample was transferred into a desiccator, and the sample was kept in the desiccator to cool to room temperature. The cooled sample (with the ashing vessel) was weighed on a balance to an accuracy of 0.001 g.

In the sample, the ash amount (W_1, %) is calculated according to the following formula:

$$W_1 = \frac{m_2 - m_0}{m_1 - m_0} \times 100\%$$

where,

m_2 – weight of the crucible with ash, g

m_0 – weight of the crucible, g

m_1 – weight of the crucible with the initial sample, g

2.3 The determination of crude fiber

1.0 g of the sample was weighed. 150 mL of 0.13 molar sulfuric acid solution was added to the sample and was boiled for 30 ± 1 minutes. At the beginning of boiling, it was stirred at a slow speed with a circular motion. After boiling, the sample was cooled to room temperature and filtered through filter paper. Then, it was washed with 10 mL of boiling (85-100℃ temperature) distilled water at least 5 times. In the next step, the residual sample was transferred to another flask, 150 mL of 0.23 molar potassium hydroxide solution was added, and the mixture was boiled for 30 ± 1 minutes. After boiling, it was cooled to room temperature. Then it was washed with hot distilled water until neutral. Then it was washed 3 times with 30 mL of acetone, each time ensuring both rapid filtration and drying with a vacuum device. The filtrate was transferred to a porcelain crucible and dried at 130℃ for 3 hours. It was cooled to room temperature in a desiccator and was weighed on an analytical balance.

The expression of the mass fraction of crude fiber (W_2, %) is calculated by the following formula:

$$W_2 = \frac{m_2 - m_3}{m_1} \times 100\%$$

where,

m_1 – weight of the sample, g

m_2 - weight of the filter paper and sample after drying, g

m_3 — weight of the filter paper, g

2.4 The determination of crude protein

1.0 g of powdered sample was poured into a Kjeldahl tube, 12 mL of sulfuric acid (H_2SO_4), and 2 Kjeldahl tablets (containing 3.5 g K_2SO_4, 0.4 g $CuSO_4$) were added. Then, it was placed in a combustion apparatus preheated to 420℃ for 1 hour. After the combustion process was completed, the tubes were cooled, and 80 mL of distilled water was added to a 250 mL flask and placed in a Kjeldahl apparatus. Then, 25 mL of 4% boric acid (H_3BO_3) and 50 mL of 40% NaOH were transferred to a Kjeldahl apparatus. The distillation process was carried out for 5 minutes. It was titrated with 0.1 M hydrochloric acid until a pink color was obtained.

The amount of nitrogen (W_n, %) is calculated by the following formula:

$$W_n = \frac{1.4007 \times (V_s - V_b) \times C_s}{m}$$

where,

W_n – Amount of nitrogen, %

V_s – amount of acid used in titration, mL

V_b – amount of acid used in blank sample, mL

C_s – molarity of acid used in titration

m – mass of sample, g

The crude protein content (W_p, %) is then calculated using the Kjeldahl factor:

$$W_p = W_n \times f_k$$

where,

W_n – Nitrogen amount;

f_k – Kjeldahl nitrogen to protein conversion factor. For feed and feed additives, this factor is 6.25.

2.5 Blank sample

0.7 g of sucrose was weighed, 2 mL of water was added, and the experiment was carried out as described above.

2.6 The determination of mineral elements

To determine the mineral elements and their amounts, powdered pomegranate peel samples of each variety were first prepared by dry ashing. The ash was moistened and dissolved with the appropriate acid mixture, nitric acid - HNO_3. The dissolved solution was filtered, and for analysis, mineral elements and their amounts were determined using an induced plasma emission spectrometer - "ICPE-9800" model device using the AOAC 984.27 method.

2.7 The determination of vitamins (B_1, B_2, C)

1 g of dried and ground sample was mixed with 25 mL of 0.1 M HCl, incubated in a water bath at 80℃ for 30 min, cooled, and centrifuged for 10 min. One milliliter of the supernatant was filtered through a 0.45 µm membrane prior to injection.

Vitamin analysis was performed using HPLC under the following conditions [14]:

Instrument: Agilent 1260 Infinity HPLC

Column: C18 reverse-phase column (250 × 4.6 mm, 5 µm)

Mobile phase: (A) 0.1% formic acid in water; (B) methanol

Gradient program:

- 0 min – 20% B
- 10 min – 50% B
- 20 min – 80% B
- 25 min – 95% B
- 30 min – 20% B

Flow rate: 1.0 mL/min

Column temperature: 30℃

Injection volume: 20 µL

Detection wavelengths:

Vitamin B_1: λ = 246 nm

Vitamin B_2: λ = 266 nm

Vitamin C: λ = 254 nm

2.8 The determination of vitamins (A, E)

1 g of sample was mixed with alcoholic KOH (10% w/v) containing BHT, saponified at 60℃ for 30 min, extracted with n-hexane, washed with distilled water, dried over Na_2SO_4, evaporated, redissolved in mobile phase, and filtered through a 0.45 µm membrane.

Vitamin A and E were analyzed by HPLC using the following conditions [14]:

Instrument: Agilent 1260 Infinity HPLC

Column: C18 reverse-phase column (250 × 4.6 mm, 5 µm)

Mobile phase: Methanol: water (95:5, v/v) (isocratic)

Gradient program:

- 0 min – 20% B
- 10 min – 50% B
- 20 min – 80% B
- 25 min – 95% B
- 30 min – 20% B

Flow rate: 1.0 mL/min
Column temperature: 30°C
Injection volume: 20 µL
Detection wavelengths:
Vitamin A: λ = 325 nm
Vitamin E: λ = 292 nm

2.9 The determination of fatty acids

Oil samples obtained from the peels of Bala Mursal, Azerbaijan Guloyshe, and Nazik Gabig pomegranate varieties using the Soxhlet method were individually weighed into a 0.5 g centrifuge tube, then 5 mL of n-hexane was added and mixed. Then 200 µl of KOH-methanol solution was added. It was mixed in a vortex device for 1 minute and allowed to stand for 5 minutes. 0.5 g of Na_2SO_4 was added and centrifuged at room temperature for 3 minutes. Then the sample oils were placed in a gas chromatography device, and the fatty acid composition was determined.

All chemical analyses were performed in triplicate (n = 3). Results are presented as mean values. One-way analysis of variance (ANOVA) was applied to evaluate differences among pomegranate varieties. No statistically significant differences were observed among the analyzed parameters ($p > 0.05$). Statistical analyses were conducted using IBM SPSS Statistics version 26.

2.10 The devices

Drying process: Chinese-made "Heat Pump Dehydrator" model "AGHD-15ELC"; grinding process: 2020 Turkish-made "Model SM 108 Super Mixer Grinder"; moisture: Polish-made "RADWAG Wagi Elektroniczne" model "MA 110.R.WH"; crude ash: According to the ISO 5984:2022 standard, by ashing at a temperature of 550°C by the 2015 German-made WiseTherm (Witeg Labortechnik GmbH) "Wisd 2" model device, crude protein: VELP SCIENTIFICA "UDK 129" model apparatus by Kjeldahl method according to ISO5983 2:2009 standard; crude oil: by the Socs plus-SCS-6AS instrument based on the Soxhlet method according to the GOST13496.15 2016 standard; crude fiber: by the Fibra plus-FES-6 tool according to ISO 6865-2015 standard; Mineral elements such as calcium, potassium, magnesium, sodium, phosphorus, iron: With the help of a "Milestone" microwave digestion system device and Shimadzu "ICPE-9800" model inductively coupled plasma emission spectrometer made in Japan, using the AOAC 984.27 analysis method; fatty acid composition: "Agilent technologies 7820A" model gas chromatography with ISO 12966-4, ISO 15884 IDF 182 standards; Vitamins A, B_1, B_2, C, E were determined according to the method described in the AOAC [14] using America-made Agilent 1260 Infinity high-pressure liquid chromatography (HPLC) [15].

3. RESULTS AND DISCUSSIONS

3.1 Chemical composition of pomegranate peels

Analyses of the peels of cultivated pomegranate varieties obtained during processing from wine factories located in the Aghsu and Goychay regions of Azerbaijan for the purpose of food supplementation allowed us to determine the presence of chemical and nutritional properties. Thus, the results of the study on the chemical and nutritional analysis of the peels of the Bala Mursal, Azerbaijan Guloyshe, and Nazik Gabig cultivated pomegranate varieties are clearly shown in Table 1. As a result of the study, differences were observed between the chemical and nutritional composition indicators of the studied varieties, depending on the varietal characteristics and growing conditions. Thus, the moisture index of the peels of the cultivated varieties was observed 8% in Bala Mursal, 9% in Azerbaijan Guloyshe, and 7% in Nazik Gabig.

Table 1. Analysis of the chemical and nutritional composition of pomegranate peels

Varieties	Moisture, %	Crude Ash, %	Crude Protein, %	Crude Oil, %	Crude Fiber, %	Calcium (mg/100 g)	Magnesium (mg/100 g)	Sodium (mg/100 g)	Phosphorus (mg/100 g)	Iron (mg/100 g)	Potassium (mg/100 g)	A (mg/100 g)	E (mg/100 g)	C (mg/100 g)	B_1 (mg/100 g)	B_2 (mg/100 g)
Bala Mursal	8	3.75	2.99	1.34	18.89	336	54	61	113	5	144	0.176	4.11	13.25	0.139	0.06
Azerbaijan Guloyshe	9	3.74	2.97	1.38	18.93	338	55	65	118	8	147	0.181	4.13	13.26	0.141	0.07
Nazik Gabig	7	3.77	2.96	1.36	18.91	333	52	63	116	7	142	0.178	4.09	13.23	0.138	0.04

Values represent the mean of three independent determinations (n = 3). No statistically significant differences were observed among pomegranate varieties for the analyzed parameters ($p > 0.05$).

During the study, the ash amount of the peels by variety was also determined. Thus, this indicator was found to be 3.75% in Bala Mursal, 3.74% in Azerbaijan Guloyshe, and 3.77% in Nazik Gabig.

The protein amount of pomegranate peels was also determined. Thus, this indicator was 2.99% in Bala Mursal, 2.97% in Azerbaijan Guloyshe, and 2.96% in Nazik Gabig.

The amount of crude oil in pomegranate peels was also determined during the study. Thus, while differences were observed between the indicators, the highest amount was found in Azerbaijan Guloyshe - 1.38%, then in Nazik Gabig- 1.36%, and in Bala Mursal - 1.34%.

In the study conducted on nutritional composition analysis, the amount of crude fiber in pomegranate peels was determined. It was clarified that the highest amount of crude fiber was in Azerbaijan Guloyshe - 18.93%, then in Nazik Gabig- 18.91%, and in Bala Mursal - 18.89%.

These indicators were suitable with analytical studies conducted on pomegranate peels in India, which revealed that the moisture amount was 7.27%, crude ash 4.32%, crude protein 3.74%, and crude fat 0.85% [16]. Akuru et al. [17] found that pomegranate peels contained 2.17% crude protein, 6.67% moisture, 4.06% crude ash, and 3.34% crude fiber. Kaushal and Kaur [18] in their study of the chemical composition of pomegranate peels, found that moisture was 11.87%, crude ash - 4.32%, crude protein - 4.45%, crude fat - 1.72%, and crude fiber - 14.33%. The presence of crude oil in pomegranate peels in the range of 1.34%-1.38% is considered favorable for their long-term storage. The crude protein amount of pomegranate peels, which is between 2.96% and

2.99%, indicates the presence of nitrogenous substances and may be useful for their use as a food supplement. The results of other studies in this direction are slightly higher than our study, but this deficiency may be compensated for by the high fiber and mineral content of pomegranate peels. In our study, the crude fiber amount of pomegranate peels was determined to be between 18.89%-18.93%. According to the results of other studies, the crude fiber amount of pomegranate peels was lower compared to Azerbaijani varieties. Ravinder Kaur and Sonia Kaushal emphasized that increasing the crude fiber amount of pomegranate peels would increase their nutritional value, which is also consistent with our study. Pomegranate peels, with their high fiber content, have a positive effect on diets and food supplements. Thus, the high crude fiber amount of pomegranate peels has properties that regulate bowel movements and improve the digestive system. In short, the crude fiber amount of pomegranate peels indicates that it is suitable for use as a food supplement.

The relatively high crude fiber content observed in the pomegranate peels (18.89–18.93%) may be attributed to varietal genetic characteristics as well as environmental conditions prevalent in the Aghsu and Goychay regions, including soil texture and climatic factors. Pomegranate peels are known to be rich in structural polysaccharides such as cellulose, hemicellulose, and lignin, which contribute to increased fiber accumulation during fruit maturation. The higher crude fiber content observed in Azerbaijani pomegranate peels compared to values reported in Indian and other international studies can be attributed to a combination of varietal genetic characteristics, cell wall components thickening, potentially influenced by prolonged sunlight exposure and moderate water stress. and regional agro-climatic conditions. From an application perspective, high fiber content enhances the suitability of pomegranate peels for use as a functional ingredient in food formulations, particularly in fiber-enriched products and dietary supplements.

3.2 Mineral composition of pomegranate peels

The peel of the pomegranate fruit is rich in biologically active substances, especially mineral elements. These minerals participate in the regulation of many physiological processes in the body and have a wide range of applications in the medical and pharmacological fields. In particular, (Calcium – Ca, Magnesium – Mg, Phosphorus – P, Potassium – K, Sodium – Na) and (Iron – Fe) are important for the normal functioning of the body.

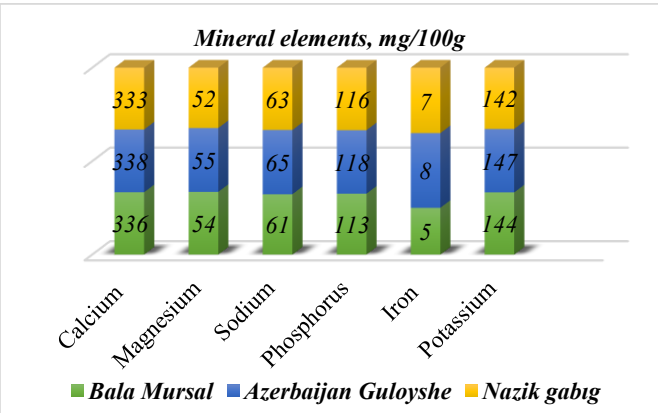

Figure 1. Amounts of mineral elements in pomegranate peels

The aim of the study is to determine the amount of macro and microelements in the peels of different pomegranate varieties and to assess their potential nutritional and industrial importance. For this purpose, an analysis was carried out to detect mineral elements in the peels obtained. Thus, differences were observed depending on the growing conditions and varietal characteristics of the varieties (Figure 1).

During the study, the calcium element in the peels of the varieties showed a sharp difference, containing the highest amount compared to other chemical indicators. It was clarified that this indicator was in Azerbaijan Guloyshe - 338 mg/100 g, in Bala Mursal - 336 mg/100 g, and in Nazik Gabig - 333 mg/100 g.

When determining the amount of magnesium in pomegranate peels, differences were observed compared to other indicators. Thus, this indicator was in Azerbaijan Guloyshe - 55 mg/100 g, in Bala Mursal - 54 mg/100 g, and in Nazik Gabig - 52 mg/100 g.

Differences were observed in the determination of the sodium amount in pomegranate peels. It was clarified that the sodium amount was in Azerbaijan Guloyshe - 65 mg/100 g, in Nazik Gabig - 63 mg/100 g, and in Bala Mursal - 61 mg/100 g.

During the analysis, the amount of another chemical indicator - phosphorus element was also determined. Thus, this element was in Azerbaijan Guloyshe - 118 mg/100 g, in Nazik Gabig - 116 mg/100 g, in Bala Mursal - 113 mg/100 g.

During the determination of the iron chemical element in pomegranate peel, changes of a certain amount was observed depending on the growing conditions and varietal characteristics. It was clarified that this indicator was in Azerbaijan Guloyshe - 8 mg/100 g, in Nazik Gabig - 7 mg/100 g, and in Bala Mursal - 5 mg/100 g.

During the study, the potassium element contained the highest amount compared to other chemical indicators. It was clarified that the highest amount was in Azerbaijan Guloyshe - 147 mg/100 g, then in Bala Mursal - 144 mg/100 g, and in Nazik Gabig - 142 mg/100 g.

Suyundikov et al. [19] observed a calcium amount of 370 mg/100 g in their studies on pomegranate peels. Azmat et al. [20], while studying the mineral composition of pomegranate peels, found calcium in the amount of 342 mg/100 g, magnesium 148.64 mg/100 g, iron 6.35 mg/100 g, and phosphorus 118.3 mg/100 g. Omer et al. [21], while determining the mineral elements, found calcium - 342 mg/100 g, iron - 6.11 mg/100 g, potassium - 150 mg/100 g, sodium - 68 mg/100 g, and phosphorus - 120 mg/100 g. These indicators are consistent with local results and provide the basis for evaluating pomegranate peels as a mineral-rich component.

Calcium and iron were present in appreciable amounts, particularly in Azerbaijan Guloyshe, highlighting the mineral-rich nature of local cultivars. The elevated calcium content suggests potential for contributing to bone health, while the iron levels exceed those reported in several international studies, underlining the nutritional relevance of Azerbaijani varieties.

The elevated calcium levels detected in the peels, particularly in the Azerbaijan Guloyshe variety (338 mg/100 g), may be associated with calcium-rich soils and favorable mineral uptake conditions in the cultivation regions. Calcium accumulation in fruit peels is closely related to soil mineral availability and translocation efficiency within the plant. Similar trends have been reported in studies conducted under

comparable agro-climatic conditions, while lower values observed elsewhere may reflect differences in soil composition and fertilization practices. The substantial calcium content reinforces the nutritional relevance of pomegranate peels as a mineral-rich by-product suitable for food and nutraceutical applications.

3.3 Vitamin profile of pomegranate peels

The amount of vitamins in dried pomegranate peels was also determined (Figure 2). As a result of the analysis, vitamins A, E, C, B_1, and B_2 were detected in pomegranate peels. Thus, the highest amount of vitamin A was found in Azerbaijan Guloyshe - 0.181 mg/100 g, then Bala Mursal - 0.176 mg/100 g, in Nazik Gabig - 0.178 mg/100 g, the highest amount of vitamin E was found in Azerbaijan Guloyshe - 4.13 mg/100 g, then in Bala Mursal - 4.11 mg/100 g, in Nazik Gabig - 4.09 mg/100 g, the highest amount of vitamin C was found in Azerbaijan Guloyshe - 13.26 mg/100 g, then in Bala Mursal - 13.25 mg/100 g, in Nazik Gabig - 13.23 mg/100 g, vitamin B 1 was found in the highest amount in Azerbaijan Guloyshe - 0.141 mg/100 g, then in Bala Mursal - 0.139 mg/100 g, a slightly lower amount in Nazik Gabig - 0.138 mg/100 g, vitamin B 2 was found in the highest amount in Azerbaijan Guloyshe - 0.07 mg/100 g, then in Bala Mursal - 0.06 mg/100 g, in Nazik Gabig - 0.04 mg/100 g.

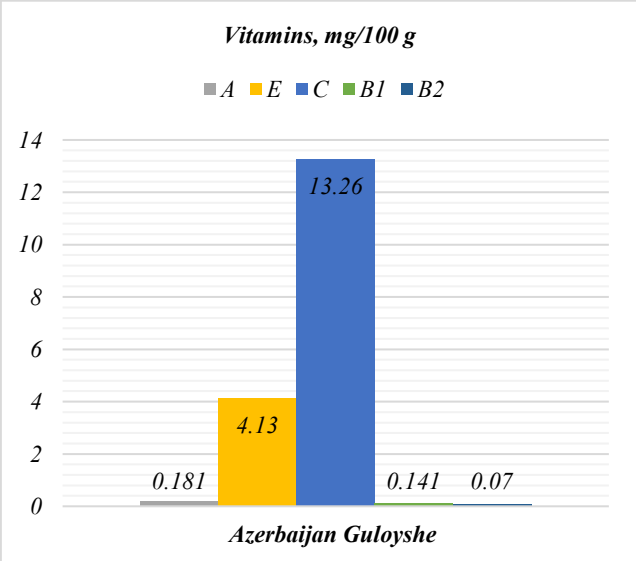

Figure 2. Amounts of vitamins in pomegranate peels

These indicators increase the potential of pomegranate peels as a functional food supplement and once again prove that they are a natural source of bioactive compounds. When comparing the results of the study with other conducted scientific studies at the international level, consistency is observed. For example, in a study conducted by Isakov et al. [22], vitamin C in the peel of the Birch pomegranate variety was found to be 12.18 mg/100 g, B_2 - 13.07 mg/100 g, and B_1 - 0.70 mg/100 g. These results are in line with our findings, especially in terms of vitamin C, but the amounts of vitamins B_2 and B_1 were higher. This difference can be explained by varietal characteristics, cultivation conditions, climate, and soil factors. At the same time, in the study of Sarkar et al. [23], vitamin A in pomegranate peel was 2.91 mg/100 g, vitamin C - 67.23 mg/100 g, B_1 - 0.11 mg/100 g, B_2 - 0.06 mg/100 g [23]. It is interesting that in this study, vitamins A and C were recorded in higher amounts. The noted differences may be due to the analysis methodology used, the drying and storage conditions of the peel, and even the determination in fresh or dry weight. Overall, both this study and other comparable international studies prove that pomegranate peels are rich in various vitamins, which is one of the main reasons for their high antioxidant potential. This increases the potential of pomegranate peels to be used as both food and medicinal products.

The vitamin profile further confirms the functional potential of the peels. Vitamins C and E—key antioxidants—were especially abundant in Azerbaijan Guloyshe, reinforcing the peel's capacity to neutralize free radicals and support immune function.

The variation in vitamin contents observed among pomegranate peel samples and between this study and previous reports can be attributed to well-defined environmental, genetic, and methodological factors rather than random numerical differences. Soil mineral composition is a key determinant, as elements such as potassium, magnesium, calcium, phosphorus, and iron regulate enzymatic reactions involved in antioxidant metabolism and vitamin biosynthesis. The strong correlations observed among these minerals indicate that mineral availability directly influences vitamin accumulation in the peel.

Climatic conditions, particularly solar radiation and temperature, affect vitamin stability and synthesis. Increased sunlight exposure enhances the production of antioxidant compounds, while thermal and water stress can stimulate vitamin C and E accumulation as part of the plant's oxidative stress response. This mechanism likely explains the higher concentrations of these vitamins in certain cultivars.

Genetic differences among cultivars represent another critical factor. Azerbaijan Guloyshe, Bala Mursal, and Nazik Gabig differ in their capacity for nutrient uptake, metabolic activity, and compound storage, leading to cultivar-specific vitamin profiles.

Sampling time and location further contribute to variability, as vitamin concentrations change during fruit maturation and depend on regional growing conditions.

Thus, the observed differences reflect systematic influences of mineral nutrition, environmental conditions, genetic background, and analytical approach, confirming the reliability of the results and the functional potential of pomegranate peels.

A number of studies have shown that the formation of substances accumulated in different parts of plants occurs independently of each other in many cases. The scarcity or abundance of a number of substances participates in the formation of others and affects their decrease or increase.

3.4 Mineral interaction and correlation analysis

During the research, the variety composition of minerals in pomegranate peels was determined, the factors affecting their formation were investigated, and the interaction of these minerals with each other was also determined. The correlation dependence among mineral substances was determined using the Pearson formula (Table 2). It was clarified that there are various forms of dependencies among these indicators. Thus, it was observed that the dependence among calcium and phosphorus (0.289), calcium and iron (0.216), magnesium and phosphorus (0.216), and magnesium and iron (0.142) was very low. Then, a moderate correlation dependence was observed among calcium and sodium (0.397), magnesium and sodium

(0.327), sodium and potassium (0.596), phosphorus and potassium (0.5), and iron and potassium (0.433). The highest correlation was found among calcium and magnesium (0.997), calcium and potassium (0.973), magnesium and potassium (0.953), sodium and phosphorus (0.993), sodium and iron (0.981), and phosphorus and iron (0.997) (Figure 3-8).

Table 2. The correlation dependence among mineral substances

r (Correlation)	Ca	Mg	Na	P	Fe	K
Ca	-	0.997	0.397	0.289	0.216	0.973
Mg		-	0.327	0.216	0.142	0.953
Na			-	0.993	0.981	0.596
P				-	0.997	0.5
Fe					-	0.433
K						-

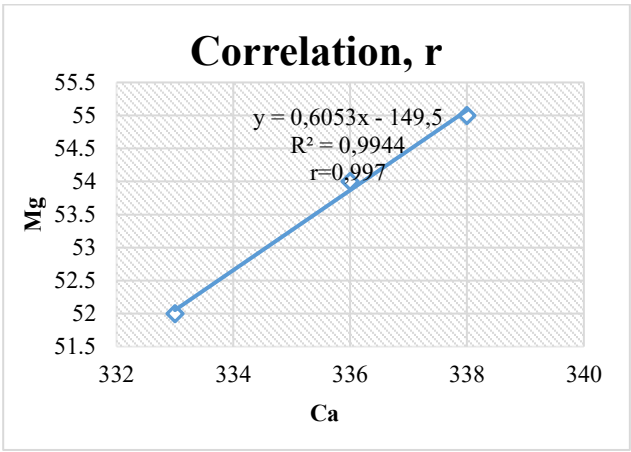

Figure 3. Correlation between Ca and Mg

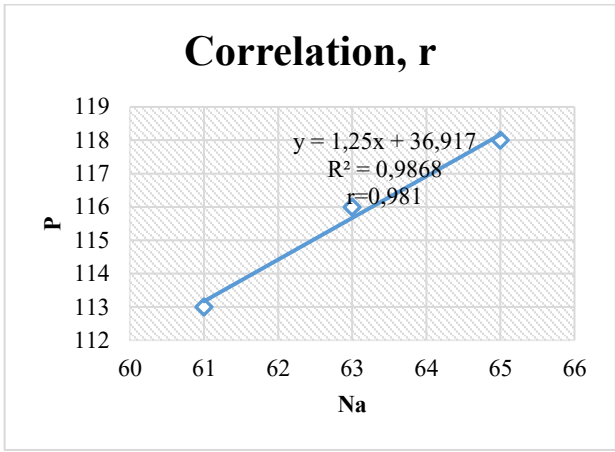

Figure 4. Correlation between Na and P

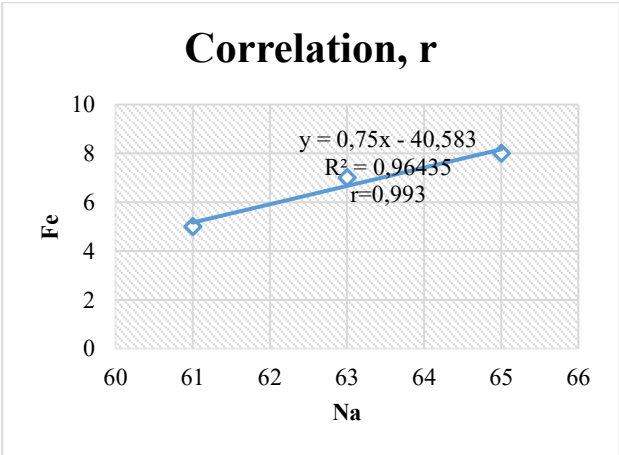

Figure 5. Correlation between Na and Fe

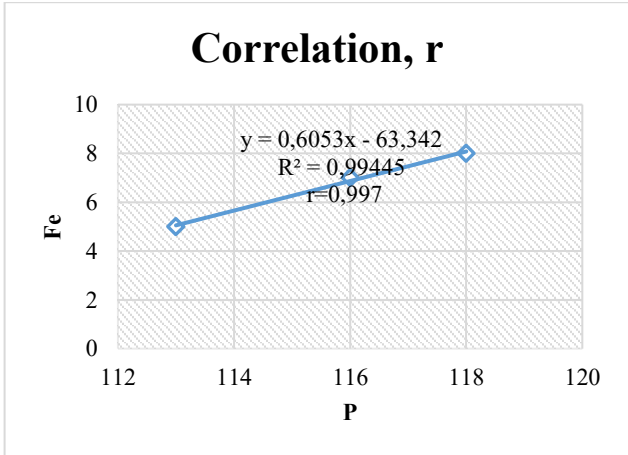

Figure 6. Correlation between P and Fe

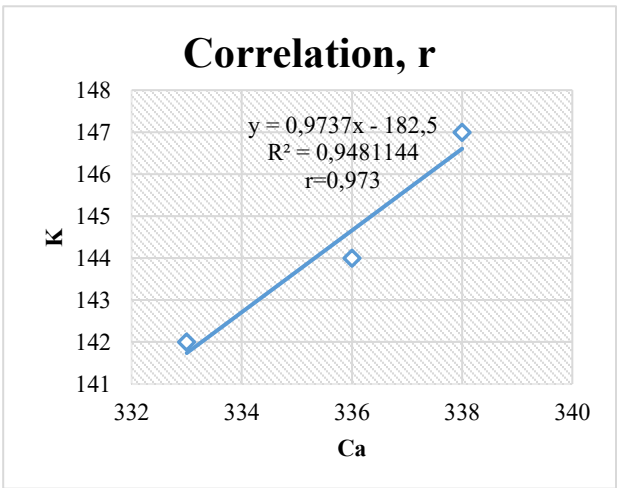

Figure 7. Correlation between Ca and K

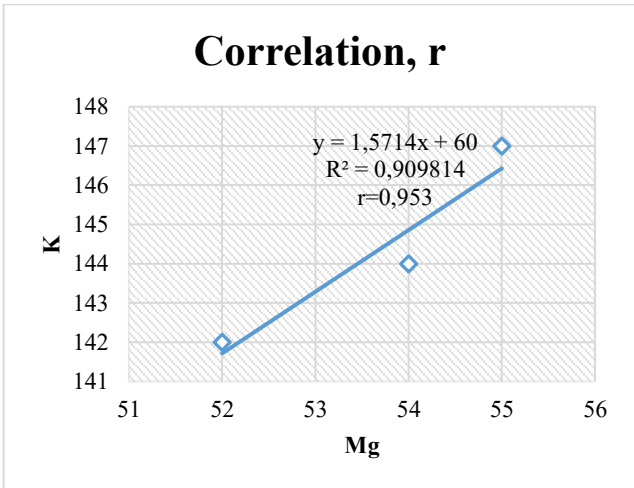

Figure 8. Correlation between Mg and K

Table 3. Fatty acids in pomegranate peels

Fatty Acids, %	Pomegranate Peel Varieties		
	Bala Mursal	Azerbaijan Guloyshe	Nazik Gabig
C14:0 (myristic)	2.98725	3.33725	3.17332
C15:0 (pentadecanoic)	0.31912	0.37894	0.32114
C16:0 (palmitic)	16.93512	17.25311	17.13674
C16:1 (palmitoleic)	0.67972	0.68763	0.68447
C18:0 (stearic)	9.56436	9.90530	9.62831
C18:1c (oleic)	20.97265	20.98883	20.80446
C18:1t (elaidic)	0.74964	0.75470	0.75226
C18:2c (linoleic)	19.12647	19.99353	19.98575
C18:2t (trans isomers of linoleic)	0.28947	0.30361	0.29968
C20:0 (arachidic)	1.04993	1.05148	1.04996
C18:3n3 (alpha-linolenic)	7.27364	7.91444	7.78012
C20:1 (eicosenoic)	7.11576	7.14878	7.12317
C18:3n6 (gamma-linolenic)	0.40178	0.42199	0.42114
C22:0 (behenic)	1.65785	1.74832	1.67236
C22:2 (docosadienoic)	2.17826	2.33762	2.32639
C24:0 (lignoceric)	0.52654	0.56868	0.53972
C20:5 (eicosapentaenoic)	1.16483	1.17275	1.16538
C24:1 (nervonic)	1.61912	1.62729	1.62521
C22:6 (docosahexaenoic)	2.32112	2.34575	2.34118
Amount of saturated fatty acids, %	33.04017	34.24308	33.52155
Amount of unsaturated fatty acids, %	64.89246	65.69692	65.30921

Fatty acid composition values are expressed as mean values of triplicate analyses (n = 3). No statistically significant differences were detected among varieties ($p > 0.05$).

3.5 Fatty acid composition of pomegranate peels

Oils were extracted from different varieties of pomegranate peels (Bala Mursal, Azerbaijan Guloyshe, and Nazik Gabig) by the Soxhlet method, and the fatty acid composition of the oils was studied. Thus, during the analysis of fatty acids, 19 fatty acids were detected in the peels of the Bala Mursal, Azerbaijan Guloyshe, and Nazik Gabig varieties (Table 3), including saturated fatty acids such as myristic, pentadecanoic, palmitic, stearic, arachidic, behenic, and lignoceric, as well as unsaturated fatty acids comprising palmitoleic, oleic, elaidic, eicosenoic, nervonic, linoleic, trans isomers of linoleic, α-linolenic, γ-linolenic, eicosapentaenoic, docosadienoic, and docosahexaenoic acids. Among the 19 identified fatty acids in the pomegranate peels, α-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) were detected as omega-3 fatty acids, whereas linoleic acid (LA), trans isomers of linoleic acid, and γ-linolenic acid (GLA) were present as omega-6 fatty acids. Omega-3 and omega-6 fatty acids are essential polyunsaturated fatty acids that play a critical role in human health, including cardiovascular protection, anti-inflammatory effects, and support for brain and eye development. The presence of these fatty acids in the peel samples indicates their potential as a valuable source for functional food ingredients and nutraceutical applications.

Thus, myristic acid was found in the amount of 3.33725% in Azerbaijan Guloyshe, 3.17332% in Nazik Gabig, and 2.98725% in Bala Mursal.

Trace amounts of pentadecanoic acid were also found in the pomegranate peel oils studied. Thus, this fatty acid accumulated in the amount of 0.37894% in Azerbaijan Guloyshe, 0.32114% in Nazik Gabig, and 0.31912% in Bala Mursal.

It was clarified that the palmitic acid amount in pomegranate peel oils is slightly higher. Thus, this fatty acid accumulated in Azerbaijan Guloyshe - 17.25311%, in Nazik Gabig- 17.13674%, and in Bala Mursal - 16.93512%.

Later, it was found that palmitoleic acid was present in small amounts in the oils. Thus, it was found in Azerbaijan Guloyshe - 0.70263%, in Nazik Gabig- 0.68447%, in Bala Mursal - 0.67972%.

Stearic acid, which belongs to the group of saturated fatty acids, was also found in small amounts in the studied pomegranate peel oils. Thus, this fatty acid constituted 9.90530% in Azerbaijan Guloyshe, 9.62831% in Nazik Gabig, and 9.56436% in Bala Mursal.

Cis and trans isomers of oleic acid were also found in pomegranate peel oils. Thus, the cis isomer of oleic acid was 20.98883% in Azerbaijan Guloyshe, 20.80446% in Nazik Gabig, and 20.97265% in Bala Mursal. The trans isomer of oleic acid (elaidic) was 0.75470% in Azerbaijan Guloyshe, 0.75226% in Nazik Gabig, and 0.74964% in Bala Mursal. Linoleic acid was also found in significant amounts in pomegranate peel oils. Thus, this fatty acid was found in the amount of 19.99353% in Azerbaijan Guloyshe, 19.98575% in Nazik Gabig, and 19.12647% in Bala Mursal.

Trans-linoleic acid was also found in trace amounts in pomegranate peel oils. Thus, this fatty acid was found in the amount of 0.30361% in Azerbaijan Guloyshe, 0.29968% in Nazik Gabig, and 0.28947% in Bala Mursal.

During the analysis, arachidic acid was found in small amounts in pomegranate peel oils. Thus, it was detected in the amount of 1.05148% in Azerbaijan Guloyshe, 1.04996% in Nazik Gabig, and 1.04993% in Bala Mursal.

During the study, α-linolenic fatty acid was also found in significant amounts in the oils. Thus, this fatty acid was found in the amount of 7.91444% in Azerbaijan Guloyshe, 7.78012% in Nazik Gabig, and 7.27364% in Bala Mursal.

Eicosenoic fatty acid, which is one of the valuable indicators for oils, was found in significant amounts. Thus, this fatty acid was found in the amount of 7.14878% in Azerbaijan Guloyshe, 7.12317% in Nazik Gabig, and 7.11576% in Bala Mursal.

During the study, γ -linolenic fatty acid was also found in the oils. Thus, this fatty acid was found in the amount of

0.42199% in Azerbaijan Guloyshe, 0.42114% in Nazik Gabig, and 0.40178% in Bala Mursal.

During the analysis, it was found that pomegranate peel oil also contains a small amount of behenic acid. Thus, this acid was detected in the amount of 1.74832% in Azerbaijan Guloyshe, 1.67236% in Nazik Gabig, and 1.65785% in Bala Mursal.

Docosadienoic fatty acid was found in certain amounts in the oils. It was clarified that this fatty acid was in Azerbaijan Guloyshe - 2.33762%, in Nazik Gabig- 2.32639%, and in Bala Mursal - 2.17826%.

Lignoceric acid was also found in trace amounts in pomegranate peel oils. Thus, this fatty acid was in Azerbaijan Guloyshe - 0.56868%, in Nazik Gabig- 0.53972%, and in Bala Mursal - 0.52654%.

Eicosapentaenoic acid was also found in insignificant amounts in the oil samples. It was detected in the amount of 1.20275% in Azerbaijan Guloyshe, 1.16538% in Nazik Gabig, and 1.16483% in Bala Mursal.

Nervonic acid was also found in trace amounts in pomegranate peel oils. It was determined that this fatty acid was in Azerbaijan Guloyshe - 1.62729%, in Nazik Gabig- 1.62521%, and in Bala Mursal - 1.61912%.

During the analysis, docosahexaenoic fatty acid was also found in small amounts in the oils. It was clarified that this fatty acid was in Azerbaijan Guloyshe – 2.34575%, in Nazik Gabig- 2.34118%, and in Bala Mursal - 2.32112%.

The results of the analysis showed that the highest fatty acid amount was found in Azerbaijani Guloyshe (Figure 9). It was clarified that unsaturated fatty acids predominated in the composition of pomegranate peels. Thus, saturated fatty acids were 34.24308% in Azerbaijan Guloyshe, 33.52155% in Nazik Gabig, and 33.04017% in Bala Mursal. Unsaturated fatty acids were found 65.69692% in Azerbaijan Guloyshe, 65.30921% in Nazik Gabig, and 64.89246% in Bala Mursal.

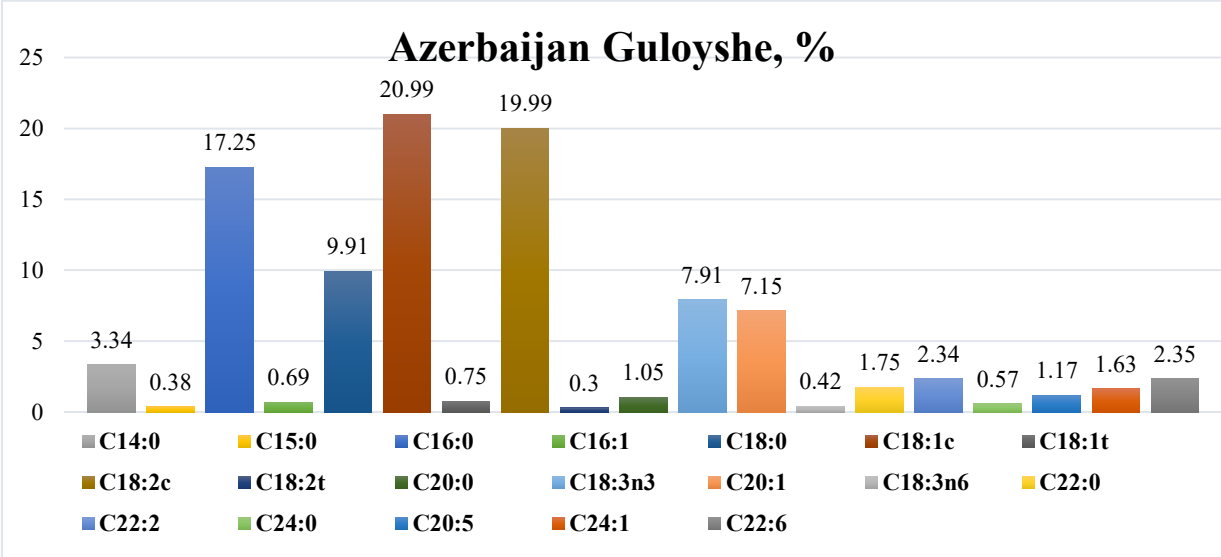

Figure 9. The fatty acid amounts in the peels of the Azerbaijan Guloyshe pomegranate

The predominance of unsaturated fatty acids (64.89–65.70%) over saturated ones reflects a lipid profile typical of plant-derived oils and may be influenced by both genetic background and environmental growing conditions [13]. Temperature, sunlight exposure, and water availability are known to modulate fatty acid biosynthesis in plant tissues. While a high proportion of unsaturated fatty acids enhances nutritional quality, it also increases susceptibility to oxidative degradation. In this context, the relatively low total oil content of pomegranate peels represents a technological advantage, reducing oxidation risk and improving storage stability for potential industrial utilization.

A high proportion of unsaturated fatty acids generally enhances the nutritional value of plant oils due to their established cardioprotective and anti-inflammatory roles. However, unsaturated lipids also increase susceptibility to oxidative degradation, which can reduce shelf-life and sensory stability [24]. The relatively low crude oil content of the peels (1.34-1.38%), therefore, represents a technological advantage, minimizing oxidation risk and facilitating long-term storage—an important factor for future food supplement applications.

When comparing the current results with other studies, some differences and similarities are observed. Thus, Grabež et al. [25] determined the fatty acid composition of pomegranate peels, and found that oleic - 13.08%, linoleic - 23.38%, linolenic - 0.19%, palmitic - 28.55%. Omer et al. [21], while determining the fatty acid composition, found linoleic - 13.89%, linolenic - 6.03%, oleic - 10.95%, and palmitic - 12.44% in pomegranate peels. From these results, it was clear that linolenic and oleic acids were higher than in other research results; palmitic and linoleic acids increased and decreased.

The results obtained during the study show that pomegranate peels can act as a source of unsaturated fatty acids that are beneficial for human health. Interestingly, although some international studies have shown that linolenic acid is dominant in pomegranate seed oil, it was found that these acids are less in the peel, but oleic and linoleic acids predominate. This difference is due to the different fat profiles in the anatomical parts of the plant. These fatty acids play an important role in the fight against cardiovascular diseases and other health problems. The oils obtained from pomegranate peels have a high fat content; they are likely to undergo oxidation and quality loss. Therefore, the use of pomegranate peels in powdered form and long-term storage conditions is important. Overall, the obtained results again confirm that pomegranate peels are not waste, but a valuable raw material with functional properties that can be used as a food additive.

4. CONCLUSIONS

No statistically significant differences were observed among the pomegranate peel samples of the three Azerbaijani varieties, although minor numerical variations were recorded depending on cultivar characteristics. Crude fiber content was consistently high, ranging from 18.89 to 18.93%. From a functional and technological perspective, fiber contents at this level are considered highly valuable for food formulations, as they improve water-holding capacity, texture, and viscosity. Such characteristics are particularly beneficial for the production of fiber-enriched bakery products and dietary supplements while also supporting digestive health, bowel regulation, and satiety in consumers. In bakery products, high dietary fiber improves dough handling, crumb structure, and moisture retention, thereby extending shelf life and supporting the development of fiber-enriched breads and biscuits.

Crude fat content remained low (1.34–1.38%) across varieties. This feature is considered advantageous for long-term storage, as lower lipid levels reduce susceptibility to oxidative degradation and enhance product stability during processing and storage.

Moderate levels of crude ash (3.74–3.77%) and crude protein (2.96–2.99%) were observed. The crude ash and crude protein amounts, ranging from respectively, indicate that pomegranate peels may contribute to mineral intake and provide nitrogen-containing compounds of nutritional relevance.

Moisture content varied between 7% and 9%, indicating the suitability of the peels for dried and powdered applications. Mineral analysis revealed calcium as the dominant macroelement in all pomegranate peel samples, with values ranging from 333 to 338 mg/100 g. Potassium was the second most abundant mineral (142–147 mg/100 g), while iron was present in lower concentrations (5–8 mg/100 g). The overall mineral profiles were comparable among the studied varieties. The elevated calcium and potassium levels highlight the potential of pomegranate peels as a natural source of essential dietary minerals, which are important for bone health, muscle function, and electrolyte balance, reducing the need for synthetic mineral fortification in functional foods.

Vitamin analysis showed the presence of vitamins A, E, C, B_1, and B_2 in all pomegranate peel samples. Vitamins C and E were detected in relatively higher amounts, with values ranging from 13.23 to 13.26 mg/100 g and 4.09 to 4.13 mg/100 g, respectively, by varieties. Azerbaijan Guloyshe exhibited slightly higher vitamin levels compared to the other varieties. These antioxidant vitamins enhance the functional value of pomegranate peels by contributing to oxidative stress reduction and improving the stability of food products in which they are incorporated. The variation in mineral and vitamin content is closely related to growth stage, soil composition, and climatic conditions, which influence nutrient uptake and biosynthesis.

Fatty acid profiling identified a total of 19 fatty acids in the pomegranate peel oils. Unsaturated fatty acids predominated, accounting for approximately 65% of total fatty acids. Oleic (20.80–20.99%), linoleic (19.13–19.99%), and α-linolenic acids (7.27–7.91%) were the major unsaturated components, whereas palmitic acid (16.94–17.25%) was the dominant saturated fatty acid.

The dominance of unsaturated fatty acids supports the nutritional quality of pomegranate peels, given their established roles in cardiovascular health and anti-inflammatory processes. The highest fatty acid levels were observed in the Azerbaijan Guloyshe variety, confirming that both genotypic characteristics and environmental growing conditions play a key role in shaping lipid composition.

Overall, the chemical composition of pomegranate peels was largely similar among the studied varieties, with high fiber content, low fat levels, and a fatty acid profile dominated by unsaturated fatty acids.

Overall, this study demonstrates that Azerbaijani pomegranate peels, previously regarded as industrial waste, represent a high-value functional raw material for the agri-food sector. Their favorable nutritional profile, technological stability, and bioactive composition support their sustainable utilization in functional foods such as fiber-enriched bakery products, fortified yogurts, herbal teas, and dietary supplements, contributing to waste valorization, human health promotion, and the development of the bioeconomy.

ACKNOWLEDGMENT

The authors gratefully acknowledge the Azerbaijan Food Safety Institute, Azerbaijan State University of Economics, and Research Institute of Viticulture and Winemaking under the Ministry of Agriculture of the Republic of Azerbaijan for providing the facilities and support necessary to conduct this research.

REFERENCES

[1] Food and Agriculture Organization (FAO). (2011). Global Food Losses and Food Waste Extent, Causes and Prevention. Düsseldorf, Germany. https://www.researchgate.net/publication/285683189.

[2] Sadigov, R.A., Macnunlu, U.K. (2023). Acquisition of value-added products from plant-based wastes. UNEC Journal of Engineering and Applied Sciences, 3(1): 69-79. https://doi.org/10.61640/ujeas.2023.0509

[3] Gómez, M., Martinez, M.M. (2018). Fruit and vegetable by-products as novel ingredients to improve the nutritional quality of baked goods. Critical Reviews in Food Science and Nutrition, 58(13): 2119-2135. https://doi.org/10.1080/10408398.2017.1305946

[4] Salimov, V., Majnunlu, U., Hasanov, R. (2024). Sustainability in the winemaking industry and the assessment of grape seed characteristics during processing: Evidence from Azerbaijan. Scientific Horizons, 27(8): 147-157. https://doi.org/10.48077/scihor8.2024.147

[5] Afaq, F., Saleem, M., Krueger, C.G., Reed, J.D., Mukhtar, H. (2005). Anthocyanin-and hydrolyzable tannin-rich pomegranate fruit extract modulates MAPK and NF-κB pathways and inhibits skin tumorigenesis in CD-1 mice. International Journal of Cancer, 113(3): 423-433. https://doi.org/10.1002/ijc.20587

[6] El Barnossi, A., Moussaid, F., Housseini, A.I. (2021). Tangerine, banana and pomegranate peels valorisation for sustainable environment: A review. Biotechnology Reports, 29: e00574. https://doi.org/10.1016/j.btre.2020.e00574

[7] Ko, K., Dadmohammadi, Y., Abbaspourrad, A. (2021). Nutritional and bioactive components of pomegranate waste used in food and cosmetic applications: A review.

Foods, 10(3): 657. https://doi.org/10.3390/foods10030657
[8] Singh, B., Singh, J.P., Kaur, A., Singh, N. (2018). Phenolic compounds as beneficial phytochemicals in pomegranate (*Punica granatum* L.) peel: A review. Food Chemistry, 261: 75-86. https://doi.org/10.1016/j.foodchem.2018.04.039
[9] El-Hadary, A.E., Ramadan, M.F. (2019). Phenolic profiles, antihyperglycemic, antihyperlipidemic, and antioxidant properties of pomegranate (*Punica granatum*) peel extract. Journal of Food Biochemistry, 43(4): e12803. https://doi.org/10.1111/jfbc.12803
[10] Ain, H.B.U., Tufail, T., Bashir, S., Ijaz, N., Hussain, M., Ikram, A., Farooq, M.A., Saewan, S.A. (2023). Nutritional importance and industrial uses of pomegranate peel: A critical review. Food Science & Nutrition, 11(6): 2589-2598. https://doi.org/10.1002/fsn3.3320
[11] Kumar, N., Pratibha, Neeraj, Sami, R., Khojah, E., Aljahani, A.H., Al-Mushhin, A.A. (2022). Effects of drying methods and solvent extraction on quantification of major bioactive compounds in pomegranate peel waste using HPLC. Scientific Reports, 12(1): 8000. https://doi.org/10.1038/s41598-022-11881-7
[12] Baradaran Rahimi, V., Ghadiri, M., Ramezani, M., Askari, V.R. (2020). Antiinflammatory and anti-cancer activities of pomegranate and its constituent, ellagic acid: Evidence from cellular, animal, and clinical studies. Phytotherapy Research, 34(4): 685-720. https://doi.org/10.1002/ptr.6565
[13] Parisi, V., Santoro, V., Donadio, G., Bellone, M.L., et al. (2022). Comparative chemical analysis of eight *Punica granatum* L. Peel cultivars and their antioxidant and anti-inflammatory activities. Antioxidants, 11(11): 2262. https://doi.org/10.3390/antiox11112262
[14] Horwitz, W., Latimer, G.W., AOAC. (2005). Official Methods of Analysis of AOAC International. Gaithersburg Maryland: AOAC International. https://crunia.udc.gal/discovery/fulldisplay?vid=34CISUG_UDC:CRUNIA&tab=CourseReserves&docid=alma991004512829707714&lang=en&context=L&adaptor=Local%20Search%20Engine&query=course_code,contains,750G01022,AND&mode=advanced&offset=0.
[15] Singh, J., Kaur, H.P., Verma, A., Chahal, A.S., et al. (2023). Pomegranate peel phytochemistry, pharmacological properties, methods of extraction, and its application: A comprehensive review. ACS Omega, 8(39): 35452-35469. https://doi.org/10.1021/acsomega.3c02586
[16] Ranjitha, J., Bhuvaneshwari, G., Terdal, D., Kavya, K. (2018). Nutritional composition of fresh pomegranate peel powder. International Journal of Chemical Studies, 6(4): 692-696.
[17] Akuru, E.A., Oyeagu, C.E., Mpendulo, T.C., Rautenbach, F., Oguntibeju, O.O. (2020). Effect of pomegranate (*Punica granatum* L) peel powder meal dietary supplementation on antioxidant status and quality of breast meat in broilers. Heliyon, 6(12): e05709. https://doi.org/10.1016/j.heliyon.2020.e05709
[18] Kaushal, S., Kaur, R. (2015). Chemical composition and antioxodant potential of pomegranate peel (*Punica Granatum* L.). İnternational Research Journal of Chemistry, 16-30.
[19] Suyundikov, U.B., Atkhamova, S., Dodayev, Q.C., Eshmatov, F., Fayzullaeva, N., Shomaksudova, K., Uzakova, S., Zokirov, K. (2024). Determination of bioactive compounds of pomegranate peel to incorporate as a functional food ingredient in food production. BIO Web of Conferences, 95: 01038. https://doi.org/10.1051/bioconf/20249501038
[20] Azmat, F., Safdar, M., Ahmad, H., Khan, M.R.J., et al. (2024). Phytochemical profile, nutritional composition of pomegranate peel and peel extract as a potential source of nutraceutical: A comprehensive review. Food Science & Nutrition, 12(2): 661-674. https://doi.org/10.1002/fsn3.3777
[21] Omer, H.A.A., Abdel-Magid, S.S., Awadalla, I.M. (2019). Nutritional and chemical evaluation of dried pomegranate (*Punica granatum* L.) peels and studying the impact of level of inclusion in ration formulation on productive performance of growing Ossimi lambs. Bulletin of the National Research Centre, 43(1)**:** 182. https://doi.org/10.1186/s42269-019-0245-0
[22] Isakov, H., Shokhrukh, O., Ibrahimjon, R. (2023). Determination of the amount of vitamins contained in pomegranate peel and their comparison. Farg'ona Davlat Universiteti, 3: 202-202. https://doi.org/10.56292/SJFSU/vol29_iss3/a202
[23] Sarkar, A., Haque, M.A., Alam, M. (2024). Unlocking the potential of pomegranate peels as a valuable source of bioactive compounds through effective drying strategies. Food Chemistry Advances, 4: 100622. https://doi.org/10.1016/j.focha.2024.100622
[24] Melgarejo, P., Núñez-Gómez, D., Martínez-Nicolás, J.J., Giordani, E., Tozzi, F., Legua, P. (2021). Fatty acids compositional variations between the edible and non-edible fruit part of seven pomegranate varieties. Food Chemistry: Molecular Sciences, 3: 100046. https://doi.org/10.1016/j.fochms.2021.100046
[25] Grabež, M., Škrbić, R., Stojiljković, M.P., Rudić-Grujić, V., et al. (2020). Beneficial effects of pomegranate peel extract on plasma lipid profile, fatty acids levels and blood pressure in patients with diabetes mellitus type-2: A randomized, double-blind, placebo-controlled study. Journal of Functional Foods, 64: 103692. https://doi.org/10.1016/j.jff.2019.103692