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BIOLOGICAL, CHEMICAL, AND PHARMACOLOGICAL PROPERTIES OF POMEGRANATE (Punica granatum L.) PEEL: A SYSTEMATIC ANALYSIS

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Abstract: Pomegranate (Punica granatum L.) peel is considered a valuable bioactive by-product generated in the agricultural industry. Recent studies have demonstrated that it contains high amounts of polyphenols, tannins, flavonoids, vitamins, and mineral elements. These compounds provide strong antioxidant, antimicrobial, and pharmacological properties. This article analyzes the chemical composition, biological activity, and potential applications of pomegranate peel in the food, pharmaceutical, and agricultural industries. The results demonstrated that pomegranate peel possesses high antioxidant activity (DPPH, ABTS, FRAP) and has promising potential as a natural preservative.

Keywords: Punica granatum, pomegranate peel, polyphenols, antioxidant, antimicrobial activity, functional food

БИОЛОГИЧЕСКИЕ, ХИМИЧЕСКИЕ И ФАРМАКОЛОГИЧЕСКИЕ СВОЙСТВА КОЖУРЫ ГРАНАТА (Punica granatum L.): СИСТЕМАТИЧЕСКИЙ АНАЛИЗ

Аннотация: Кожура граната (Punica granatum L.) считается ценным биологически активным побочным продуктом сельского хозяйства. Недавние исследования показали, что она содержит большое количество полифенолов, дубильных веществ, флавоноидов, витаминов и минеральных элементов. Эти соединения обладают сильными антиоксидантными, противомикробными и фармакологическими свойствами. В данной статье анализируются химический состав, биологическая активность и потенциальные области применения кожуры граната в пищевой, фармацевтической и сельскохозяйственной промышленности. Результаты показали, что кожура граната обладает высокой антиоксидантной активностью (DPPH, ABTS, FRAP) и имеет многообещающий потенциал в качестве натурального консерванта.

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Ключевые слова: Punica granatum, кожура граната, полифенолы, антиоксидант, антимикробная активность, функциональные продукты питания

INTRODUCTION

Pomegranate (Punica granatum L.) is one of the oldest cultivated plants and is widely distributed in subtropical and tropical climatic regions [1]. Central Asia and Iran are considered to be its native regions. The pomegranate tree is a perennial plant distinguished by its drought tolerance and adaptability to various soil conditions. Scientific sources describe pomegranate not only as a food source but also as a medicinal plant [2].

Morphologically, the pomegranate fruit has a complex structure consisting of a hard outer peel, internal membranes, and seeds. The fruit contains carbohydrates, organic acids, vitamins (mainly vitamin C), mineral substances, and biologically active compounds [3,4]. In addition, numerous studies have reported that pomegranate fruit has high nutritional and dietary value [4,5]. (Figure 1)

Pomegranate arils are considered the most valuable part of the fruit. They consist of juicy tissue and mainly contain sugars such as fructose and glucose, organic acids, and antioxidant compounds. According to scientific studies, pomegranate seeds contain anthocyanins, which provide the characteristic red color of the fruit and exhibit antioxidant activity [6].

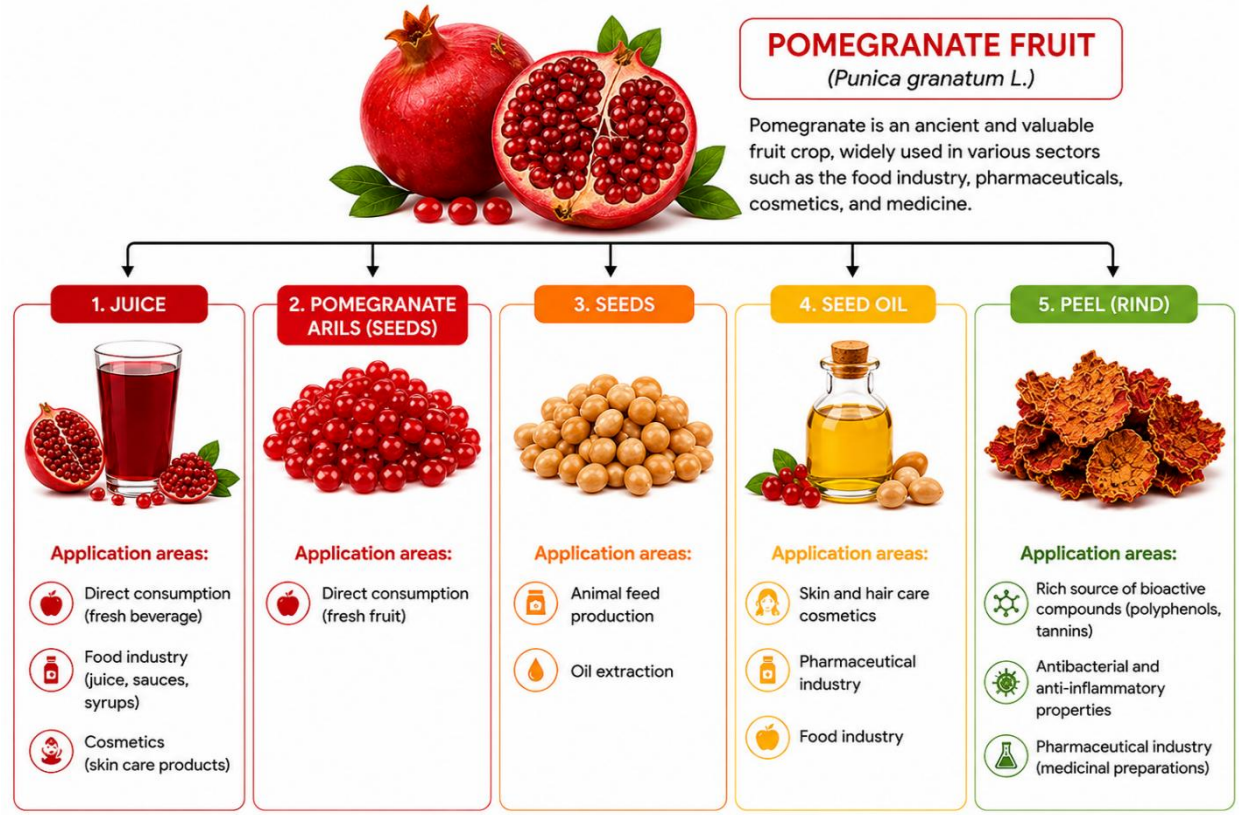

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Figure 1. Products obtained from pomegranate fruit and their characteristics

Pomegranate juice has particular importance as a functional food product. It is rich in biologically active compounds beneficial to human health and has been found to exhibit antioxidant, anti-inflammatory, and positive cardiovascular effects [7]. Therefore, pomegranate juice is widely used in the food industry.

At the same time, a large amount of peel waste is generated during pomegranate processing. Previously, these wastes were considered of low importance; however, today they are being studied as valuable sources of low importance; however, today they are being studied as valuable sources of biologically active compounds. Pomegranate peel contains high concentrations of polyphenols, tannins, and flavonoids, which possess strong antioxidant properties [8].

Studies have shown that pomegranate peel extracts exhibit antibacterial, antioxidant, and pharmacological activities. For example, the studies conducted by Al-Zoreky [9] demonstrated the inhibitory effect of pomegranate peel against pathogenic microorganisms. Furthermore, research by Singh et al. [10] reported its high free radical scavenging activity.

Currently, the possibilities of using pomegranate peel as a functional additive in the food industry, as a source of biologically active compounds in pharmaceuticals, and as a valuable raw material in biotechnology are being extensively investigated [11]. Therefore, comprehensive investigation of the chemical composition and functional properties of pomegranate peel is considered one of the important current scientific issues. The composition of pomegranate peel is presented in the following table (Table 1).

Table 1. Main Composition of Pomegranate Peel

№	Parameters	Amount (on dry matter basis)	References
1	Moisture	5–12%	Viuda-Martos et al., 2010 [11]; Mphahlele et al., 2014 [12]
2	Protein	3–8%	Singh et al., 2018 [10]; Gullón et al., 2016 [13]
3	Fat	1–3%	Fischer et al., 2011 [14]; Akhtar et al., 2014 [15]
4	Ash	5–10%	Al-Zoreky, 2009 [9]
5	Carbohydrates	50–65%	Viuda-Martos et al., 2010 [11]
6	Dietary fiber	20–35%	Gullón et al., 2016 [13]

As can be seen from the table above, according to the literature analysis, carbohydrates and dietary fiber constitute the major components of pomegranate peel. Researcher Gullón [13] described it as a “functional fiber source” because it

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positively affects the texture of food products and the digestive process. According to the studies conducted by Singh [10] and Akhtar [15], the protein and fat contents of pomegranate peel are relatively low, which makes it an important low-calorie functional ingredient.

In addition, the ash content of pomegranate peel is around 5–10%, indicating the presence of mineral elements such as K, Ca, and Mg. Al-Zoreky [9] identified this as a factor that enhances its technological value. Furthermore, the low moisture content of dried pomegranate peel (5–12%) demonstrates that it possesses optimal characteristics for long-term storage and industrial processing [11].

Analysis of Vitamins, Macro-, and Microelements in Pomegranate Peel

In recent years, the content of vitamins in pomegranate peel and their biological significance have been extensively studied by many researchers. These studies have mainly focused on determining the presence and quantitative levels of antioxidant vitamins—particularly vitamins C, E, and B-group vitamins—as well as various macro- and microelements [8,9,10,11,14,15]. (Table 2)

Table 2. Content of Vitamins, Macro-, and Microelements in Pomegranate Peel

№	Components	Amount (mg/100 g)	Biological Function
	Vitamins		
1	Vitamin C (ascorbic acid)	10–25	Strong antioxidant
2	Vitamin A (β-carotene)	0.1–0.5	Enhances immunity
3	Vitamin E (tocopherol)	0.5–1.5	Cellular protection
4	Vitamin B1 (thiamine)	0.04–0.1	Metabolism regulation
5	Vitamin B2 (riboflavin)	0.03–0.08	Energy production
6	Vitamin B3 (niacin)	0.3–0.7	Enzyme activity
7	Vitamin B6	0.1–0.3	Nervous system function
	Macroelements		
8	Potassium (K)	150–300	Cardiac function
9	Calcium (Ca)	40–100	Bone health
10	Magnesium (Mg)	20–60	Enzymatic functions
11	Phosphorus (P)	30–80	Energy metabolism
12	Sodium (Na)	5–20	Water balance
	Microelements		
13	Iron (Fe)	1–5	Blood formation
14	Zinc (Zn)	0.3–1.0	Immune function
15	Copper (Cu)	0.2–0.6	Enzymatic activity
16	Manganese (Mn)	0.5–2.0	Metabolism

The above data indicate that one of the most abundant vitamins found in pomegranate peel is vitamin C (ascorbic acid). For example, Elfalleh [8] reported

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that the vitamin C content in dried pomegranate peel ranged from 12–20 mg/100 g. These findings demonstrate that vitamin C plays an important role in the antioxidant activity of pomegranate peel. Similarly, studies by Viuda-Martos [11] showed that the vitamin C content in pomegranate peel ranged between 10–25 mg/100 g, and it was emphasized that this value may vary depending on processing methods such as drying and storage.

Vitamin E (tocopherol) has also been detected in pomegranate peel, although in relatively small amounts. According to the studies conducted by Singh [10], the amount of vitamin E is around 0.5–1.2 mg/100 g, and it participates in protecting cell membranes from oxidative damage. Beta-carotene (provitamin A) is also present in pomegranate peel. Elfalleh [8] reported that the β-carotene content ranged from 0.1–0.4 mg/100 g. This finding supports the immune-enhancing properties of pomegranate peel.

A number of studies have also been carried out on B-group vitamins. According to the research conducted by Lansky and Newman [7], the following amounts were determined:

- B1 (thiamine): 0.04–0.08 mg/100 g
- B2 (riboflavin): 0.03–0.07 mg/100 g
- B3 (niacin): 0.3–0.6 mg/100 g
- B6: 0.1–0.25 mg/100 g

These vitamins are involved in energy metabolism and enzymatic processes.

Research findings indicate that although the vitamin content in pomegranate peel is lower than that in the pulp and juice, these vitamins, together with polyphenols, exhibit a strong synergistic antioxidant effect [11].

At the same time, it has been established that the vitamin content is influenced by factors such as pomegranate variety, climatic growth conditions, drying methods, and storage duration. In particular, drying at high temperatures has been scientifically proven to reduce the amount of vitamin C [14].

Analysis of scientific literature shows that among the macroelements, potassium (K) is found in the highest concentration in pomegranate peel. For example, Elfalleh et al. [8] reported potassium levels ranging from 200–300 mg/100 g. Potassium plays an important role in maintaining water-electrolyte balance and regulating cardiac function in the human body. Calcium (Ca) is also present in significant amounts in pomegranate peel. According to Viuda-Martos [11], its content ranges from 40–100 mg/100 g, contributing to the strength of bones and teeth.

The magnesium (Mg) content has been reported to range from 20–60 mg/100 g [14]. Magnesium participates in numerous enzymatic reactions and plays a significant role in energy metabolism. In addition, the phosphorus (P) content ranges from 30–80 mg/100 g and is important in cellular energetics [8,11].

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Pomegranate peel also contains microelements which, despite being present in small quantities, possess high biological activity. In particular, iron (Fe) content is around 1–5 mg/100 g and is involved in blood formation [10]. Zinc (Zn) content ranges from 0.3–1.0 mg/100 g and plays an important role in immune system function. Furthermore, copper (Cu) and manganese (Mn) were found at levels of 0.2–0.6 mg/100 g and 0.5–2.0 mg/100 g, respectively [7]. These elements function as cofactors in enzymatic reactions. Sodium (Na) content is relatively low (5–20 mg/100 g), which broadens its application as a dietary product [8].

The mineral composition of pomegranate peel depends on several factors, and it has been noted that drying and grinding processes may alter the bioavailability of certain mineral elements [10]. In addition, minerals present in pomegranate peel interact with polyphenols, thereby enhancing their antioxidant activity [6].

Antioxidant and Antiradical Activity of Pomegranate Peel

Pomegranate (Punica granatum L.) peel has been extensively studied as a natural raw material possessing high antioxidant and antiradical activity. These properties are mainly associated with the presence of polyphenols, tannins, flavonoids, and organic acids in its composition. (Figure 2)

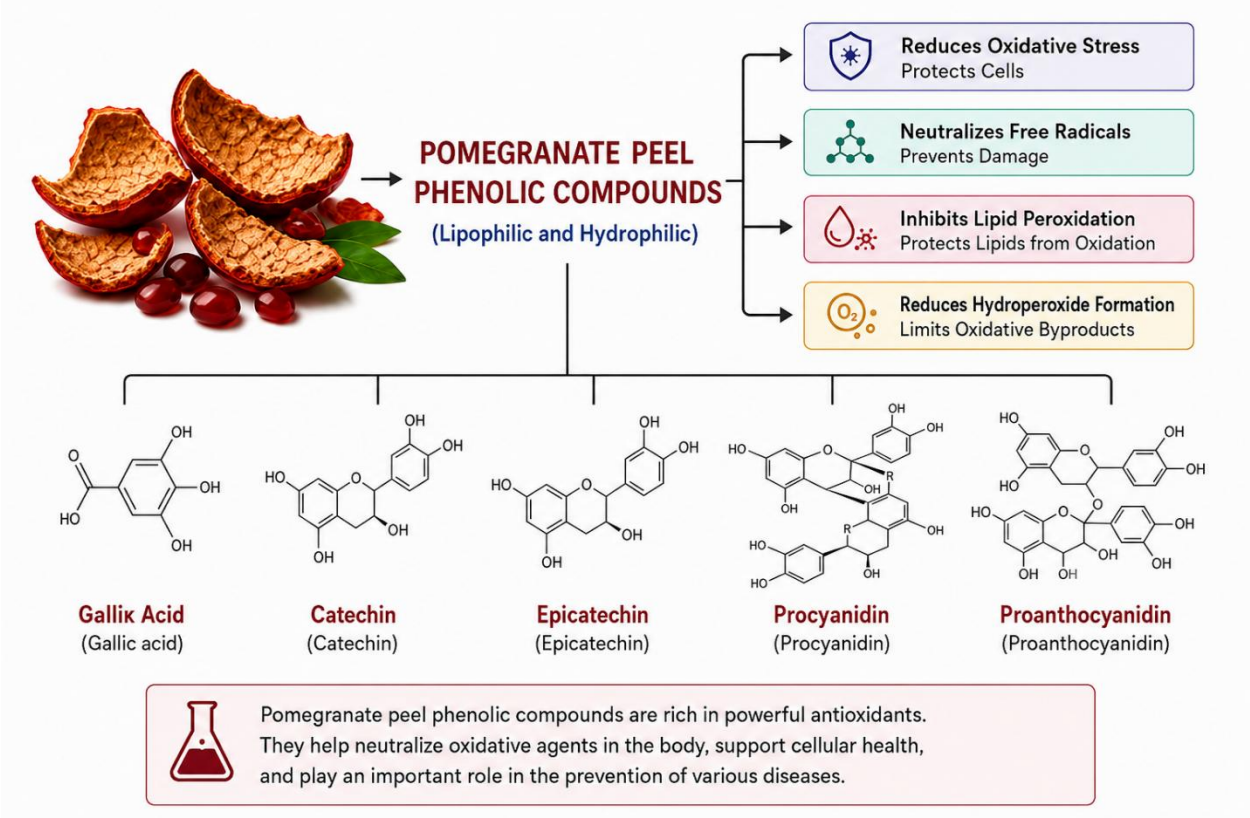

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Table 3. Literature review of the antioxidant and antiradical activity of pomegranate peel

References	Research object and extract type	Methods used	Main results	Scientific analysis and conclusion
Aviram Michael et al. [16]	Pomegranate peel polyphenolic extract	DPPH, lipid peroxidation	Exhibited high antioxidant activity and effectively neutralized free radicals	Ellagitannins and punicalagins were identified as the main antioxidant compounds in pomegranate peel. The extract activity was evaluated as higher than many synthetic antioxidants.
Negi Pradeep Singh et al. [17]	Methanolic pomegranate peel extract	DPPH, FRAP	Antiradical activity increased in a concentration-dependent manner	A strong correlation between phenolic content and antioxidant activity was demonstrated.
Li Yan et al. [18]	Aqueous and alcoholic peel extracts	ABTS, DPPH	Alcoholic extracts showed higher antioxidant activity	Polyphenols were more efficiently extracted by polar solvents, enhancing antiradical efficiency.
Singh Bharat et al. [10]	Dried pomegranate peel powder	FRAP, ORAC	High reducing power was observed	Low-temperature drying methods were found to better preserve biologically active compounds.
Elfalleh Walid et al. [8]	Different pomegranate peel varieties	DPPH, β-carotene bleaching assay	Significant differences were observed among varieties	Red-colored peel varieties contained higher amounts of phenols and flavonoids.
Akhtar Shahid et al. [15]	Ethanolic pomegranate peel extract	Inhibition of NO• and superoxide radicals	Effectively reduced reactive oxygen species	The extract was confirmed to have protective properties against oxidative stress.
Fischer Ulrike et	Peel polyphenol concentrate	DPPH, ABTS,	Showed strong performance as	It was suggested as a potential alternative

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al. [14]		ORAC	a natural antioxidant	to synthetic antioxidants in the food industry.
Pagliarulo Chiara et al. [19]	Nanoencapsulated pomegranate peel extract	DPPH, FRAP	Increased antioxidant stability	Nanoencapsulation improved the preservation of bioactive compounds and prolonged antiradical activity.

The literature analysis presented in the above table shows that pomegranate peel has a high level of antioxidant and antiradical activity, which is mainly explained by its richness in polyphenolic compounds such as punicalagin, ellagic acid, gallic acid, and flavonoids. Studies using DPPH, ABTS, FRAP, and ORAC methods have confirmed the strong free radical scavenging ability of pomegranate peel extracts.

It has also been reported that antioxidant activity is closely related to the extraction method, type of solvent, drying conditions, and pomegranate variety. In particular, alcoholic extracts show higher antiradical efficiency compared to aqueous extracts. In recent years, research on nanoencapsulation technologies has been actively developing to improve the stability of pomegranate peel polyphenols and enhance their biological effectiveness. These findings indicate that pomegranate peel is a promising source for use in functional foods, pharmaceuticals, and natural preservatives.

Pharmacological properties of pomegranate peel and its significance in folk medicine

Pomegranate peel has long been considered one of the natural medicinal raw materials widely used in folk medicine [20]. Its healing properties are also mentioned in Eastern medical sources, including the works of Abu Ali ibn Sina, where the effectiveness of pomegranate peel in intestinal diseases, parasitic infections, and inflammatory conditions is emphasized [21].

Modern scientific studies have thoroughly investigated the biological activity of pomegranate peel and have provided scientific justification for its pharmacological properties. In particular, Al-Zoreky [9] reported the broad-spectrum antimicrobial activity of pomegranate peel extracts. The researcher identified strong inhibitory effects against pathogens such as Escherichia coli, Staphylococcus aureus, and Salmonella. This scientifically supports the potential use of pomegranate peel in treating intestinal infections and oral diseases.

The gastroenterological effects of pomegranate peel have also been widely studied. In the research of Lansky and Newman [7], it was noted that tannins in its composition exert an astringent effect on the intestinal mucosa, reducing fluid secretion in cases of diarrhea. At the same time, studies by Prakash [22]

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demonstrated that pomegranate peel extracts are effective in reducing intestinal inflammation.

In addition, several studies have investigated its anthelmintic properties. Seeram [6] reported that bioactive compounds in pomegranate peel exhibit anti-parasitic effects by disrupting parasite metabolism. Ahmed [23] also confirmed the high efficacy of pomegranate peel extracts against helminths.

From a dermatological perspective, the wound-healing and skin-related benefits of pomegranate peel are of particular importance. Elfalleh [8] experimentally demonstrated its anti-inflammatory and regenerative effects. Murthy [24] further showed that pomegranate peel extracts stimulate collagen synthesis and accelerate wound healing.

The effectiveness of pomegranate peel in oral diseases has also been scientifically proven. Bhadbhade [25] reported that mouth rinses based on pomegranate peel are effective in reducing gingivitis and stomatitis. This effect is explained by the antibacterial properties of tannins and flavonoids present in pomegranate peel.

Studies on antioxidant activity further confirm the high biological value of pomegranate peel. Li [18] found that the polyphenols in pomegranate peel have strong free radical scavenging ability, making it an important natural source for reducing oxidative stress.

In folk medicine, decoctions and remedies prepared from pomegranate peel have traditionally been used for the following conditions:

- diarrhea and intestinal infections
- cough and colds
- skin diseases
- inflammatory conditions
- oral cavity diseases

However, studies by Ismail et al. [26] indicate that high doses of pomegranate peel consumption may have toxic effects in some cases. Therefore, the use of pomegranate peel for medicinal purposes should follow scientifically established dosage guidelines.

Furthermore, Viuda-Martos [11] highlighted the potential use of pomegranate peel as a functional food ingredient and natural preservative. This demonstrates its transition from traditional folk medicine to industrial applications.

Importance in the Food Industry

In recent years, the demand for natural preservatives, antioxidants, and functional ingredients in the food industry has been increasing. In this regard, pomegranate peel is considered not merely agro-waste but a high-value bioactive raw material. A number of scientific studies have confirmed its technological and functional significance in food products [11,14].

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According to the literature review, pomegranate peel extract is effective in slowing oxidation processes in meat products. Turgut [27] demonstrated that pomegranate peel extract significantly reduces lipid oxidation in sausage products. Similarly, Devatkal [28] reported that it extends the shelf life of meat products as a natural antioxidant. Pateiro [29] also found that the addition of pomegranate peel decreases the oxidation index of products, making it a potential alternative to synthetic antioxidants.

In the dairy industry, pomegranate peel extract has been studied as a functional additive. Abd El-Aziz [30] showed that adding pomegranate peel extract to yogurt improves its microbiological stability. El-Said [31] reported an extended shelf life and increased antioxidant activity in dairy products. Furthermore, Gullón [32] found a significant improvement in the functional value of probiotic products enriched with pomegranate peel.

Pomegranate peel is also widely used in the beverage industry as a natural colorant and bioactive additive. Gullón [32] identified it as a natural pigment source and a potential alternative to synthetic dyes. Singh [10] also reported its ability to ensure color stability in beverage products.Its importance as a natural preservative has been confirmed by Al-Zoreky [9], who identified strong antimicrobial activity in pomegranate peel extract. Negi and Jayaprakasha [35] further emphasized its potential use as a natural preservative against bacteria and fungi.

The literature analysis shows that pomegranate peel has broad potential in the food industry as a natural antioxidant, antimicrobial preservative, dietary fiber source, natural colorant, and functional ingredient. Its main advantage is the ability to partially or fully replace synthetic additives while increasing the biological value of food products. However, for wider industrial application, improvements in extraction technologies and optimization of sensory properties are required.

Characteristics of Use as Feed (Compound Feed Ingredient)

Today, the diversification and cost reduction of feed resources in agriculture is becoming increasingly important. This has stimulated the expansion of scientific research on the use of agro-industrial by-products, particularly pomegranate (Punica granatum L.) peel. Literature reports indicate that this raw material is an effective functional bio-additive in compound feed for livestock [11,13,32].

The main valuable feature of pomegranate peel is its rich biochemical composition. It contains high levels of dietary fiber, polyphenols, and tannins, which provide antioxidant and antimicrobial properties [10,14]. Therefore, it is considered not only a feed additive but also a biologically active substance that influences metabolic processes in animal organisms.

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From the perspective of rumen fermentation, tannins in pomegranate peel play an important role. According to Makkar [36], tannins reduce protein degradation and improve its delivery to the intestine. This enhances protein utilization efficiency in cattle and sheep diets. It has also been reported that diets containing pomegranate peel improve digestive processes.

Studies on productivity indicators have also shown positive results. Patra and Saxena [37] found improved milk quality and increased antioxidant status in dairy cows. Besharati and Taghizadeh [38] reported improved weight gain and feed conversion efficiency in sheep. These findings confirm the effectiveness of pomegranate peel as a functional feed ingredient.

At the same time, pomegranate peel also plays an important role in reducing microbiological risks. Al-Zoreky [9] demonstrated its strong antimicrobial activity, which inhibits the growth of pathogenic bacteria. Surai [39] also noted that its antioxidant effects increase stress resistance in animal organisms. These properties are important in terms of providing a natural alternative to antibiotics.

From an economic and environmental perspective, pomegranate peel is considered agro-waste, and its inclusion in feed aligns fully with the principles of circular agriculture. FAO (2019) [40] reports highlight the recycling of such by-products as an important direction for solving feed resource challenges.

However, literature analysis also shows that the high tannin content of pomegranate peel may negatively affect feed intake when used in excessive amounts [36]. Therefore, proper dosage and technological processing are essential when incorporating it into feed formulations.

CONCLUSION

The literature review indicates that pomegranate (Punica granatum L.) peel is a natural raw material rich in bioactive compounds. It contains high levels of polyphenols, tannins, flavonoids, vitamins, and mineral elements. The synergistic action of these compounds provides strong antioxidant, antimicrobial, anti-inflammatory, and pharmacological activities.

Pomegranate peel is not only considered an agricultural waste product but also a functional ingredient with high added value and significant scientific and practical importance. In the food industry, it can be used as a natural preservative, antioxidant, and source of dietary fiber. In the pharmaceutical field, it is regarded as a promising raw material for the development of antimicrobial and therapeutic agents. In addition, in animal husbandry, its positive effects on metabolic processes have been reported when used as a feed additive.

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However, to expand its practical application, it is necessary to optimize extraction technologies, improve the stability of bioactive compounds, and thoroughly investigate safety and dosage-related aspects.

Overall, pomegranate peel is an important bioresource for the "waste-to-value" approach within the framework of sustainable development. In the future, it is expected to be widely used in the production of functional foods and natural medicinal products.

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Asqarov I.R. Dalillarga asoslangan xalk tabobat usullari. Toshkent, Fan va texnologiyalar nashriyot mat’baa- uyi, 2022 y. 67 - b.**Figure 2. Phenolic**