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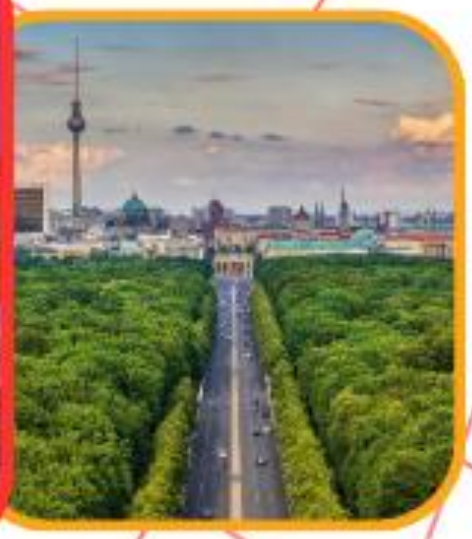

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POMEGRANATE PEEL-DERIVED BIOACTIVE SYSTEMS: CHEMICAL CHARACTERISTICS AND AGROBIOTECHNOLOGICAL POTENTIAL

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Abstract. This article discusses the chemical composition and coordination properties of biologically active components present in pomegranate (Punica granatum L.) peel. The potential of polyphenols, flavonoids, and tannins contained in pomegranate peel to form bioactive systems with metal ions was analyzed. The obtained results demonstrated that pomegranate peel can be considered a promising natural raw material for the development of environmentally friendly biochelates and micronutrient-based agrobiotechnological preparations.

Keywords: pomegranate peel, polyphenols, flavonoids, bioactive systems, biochelates, bioligands, coordination complexes, antioxidant activity, agrobiotechnology, micronutrients.

In recent years, increasing attention has been directed toward biochelate systems based on natural polyphenolic compounds. In particular, the ability of phenolic ligands derived from plant waste materials to stabilize metal ions serves as an important scientific basis for the development of environmentally safe micronutrient preparations. From this perspective, investigating the coordination activity of biologically active components contained in pomegranate peel represents one of the promising interdisciplinary fields at the intersection of bioorganic chemistry and agrobiotechnology.

At present, the development of next-generation bioactive systems based on environmentally friendly, biologically active, and renewable natural raw materials has become one of the priority directions in modern chemistry, biotechnology, and agrotechnology. In particular, obtaining high value-added biologically active products from plant waste generated in agriculture and the food industry has gained considerable scientific and practical significance [1]. In this regard, the comprehensive investigation of phenolic compounds, flavonoids, and other bioactive constituents present in fruit peels has attracted substantial scientific interest.

Uzbekistan is considered one of the major pomegranate-producing regions in Central Asia. Pomegranate fruits are widely utilized in the food industry and various sectors of the national economy. However, large quantities of peel waste are generated during pomegranate processing. The majority of this waste remains underutilized and continues to represent an environmental concern [2]. Recent studies have demonstrated that pomegranate peel is not merely an agricultural by-product, but also an important source of biologically active compounds [3].

Scientific literature reports that pomegranate peel contains high concentrations of polyphenols, ellagitannins, flavonoids, catechins, and gallic acid derivatives [4]. These compounds possess strong antioxidant and reducing properties and are characterized by their ability to neutralize free radicals [5]. In particular, the biological activity of tannins present in pomegranate peel has been reported to be significantly higher than that of other parts of the fruit [6].

One of the most important characteristics of phenolic compounds is their ability to form coordination bonds with metal ions. The hydroxyl and carbonyl groups present in polyphenolic structures act as donor centers, resulting in the formation of stabilized coordination systems with metal ions [7]. Such bioactive complexes exhibit several advantages, including high biocompatibility, good water solubility, and environmental safety [8].

In recent years, the environmental problems associated with synthetic chelating agents based on EDTA, DTPA, and EDDHA have been widely discussed in scientific literature. These compounds are resistant to biodegradation and may persist in soil and aquatic environments for extended periods [9]. Therefore, the development of biochelates and biologically active coordination systems based on natural polyphenols is considered one of the promising directions in agrobiotechnology [10].

The aim of this study is to scientifically elucidate the chemical composition of pomegranate peel, its biologically active components, and the prospects for developing bioactive coordination systems based on these compounds.

Chemical Composition of Pomegranate Peel

Pomegranate peel represents a natural bioorganic system characterized by a complex chemical composition. According to numerous studies, it contains polyphenols, flavonoids, ellagitannins, anthocyanins, organic acids, and other biologically active components [11]. In particular, ellagic acid and punicalagin derivatives are recognized as the major phenolic constituents of pomegranate peel [12].

The hydroxyl groups present in phenolic compounds exhibit high reducing activity and play a significant role in the formation of antioxidant systems [13]. Furthermore, the aromatic structure of flavonoids and the presence of multiple functional hydroxyl groups enhance their ability to form coordination bonds with metal ions [14].

Tannins contained in pomegranate peel are high-molecular-weight polyphenolic compounds distinguished by their capability to stabilize metal ions [15]. Therefore, the phenolic constituents of pomegranate peel can be considered promising natural ligands for the development of bioactive coordination systems.

Mechanism of Formation of Bioactive Coordination Systems

The coordination activity of phenolic compounds is closely associated with their molecular structure. The hydroxyl and carbonyl groups present in polyphenolic compounds act as donor centers by providing electron pairs to metal ions [16]. As a result, a stabilized coordination environment is formed around the metal ions.

In particular, the presence of multiple functional coordination centers in flavonoids and tannins enables them to actively participate as polydentate ligands [17]. In such systems, metal ions bound to organic ligands are converted into biologically active and water-soluble forms.

Another important characteristic of coordination systems based on natural polyphenols is their antioxidant activity. Phenolic compounds enhance the stability of biochelate systems by stabilizing the oxidation–reduction equilibrium of metal ions [18].

Agrobiotechnological Prospects

Bioactive systems based on pomegranate peel possess considerable potential for the development of micronutrient preparations in agriculture. The forms of metal ions bound to organic ligands are more readily absorbed by plants, thereby enhancing the biological efficiency of micronutrients [19].

In particular, biochelates based on iron, zinc, copper, and manganese ions contribute to the activation of plant metabolism, increase the intensity of photosynthesis, and improve resistance to various stress factors [20]. Compared with synthetic analogues, biochelates derived from natural polyphenols demonstrate superior environmental safety and biodegradability [21].

Furthermore, bioactive systems derived from pomegranate peel may also find applications in pharmaceuticals, food technology, and bioorganic chemistry. Their antioxidant and coordination properties are of significant importance in the development of biologically active preparations.

Conclusion

In this study, the chemical composition and biologically active components of pomegranate peel were scientifically analyzed. The findings demonstrated that the polyphenols, flavonoids, and tannins present in pomegranate peel are biologically active compounds characterized by high antioxidant and coordination activity.

The ability of phenolic compounds to form stabilized coordination systems with metal ions allows pomegranate peel to be considered a promising natural raw material for the synthesis of bioligands and biochelates. The obtained results indicate the high potential of pomegranate peel-based bioactive systems for applications in agrobiotechnology, coordination chemistry, and the development of environmentally safe micronutrient preparations.

Furthermore, the production of bioactive complexes through the deep processing of plant waste is of considerable ecological and economic importance, making this field a promising platform for future scientific research.

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