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BIOREGIONAL, BIOECOLOGICAL, AND POTENTIAL MEDICINAL SIGNIFICANCE OF SHARON (*Diospyros* L. SPECIES): PLANT ADAPTATION AND BIOLOGICAL CHARACTERISTICS

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Abstract. The paper studies the biogeographical and bioecological characteristics of persimmon species belonging to the genus *Diospyros* L. under diverse soil-climatic conditions in Azerbaijan. Three taxa were analysed - *Diospyros kaki* (Oriental persimmon), *Diospyros Lotus* (Caucasian persimmon) and *Diospyros virginiana* (American persimmon) - with emphasis on their eco-biological traits, regional distribution and adaptive capacity. Concentrations of macro- and micro-elements in persimmon fruits were quantified by X-ray fluorescence spectroscopy, enabling the delineation of areas rich in medicinally valuable germplasm and informing strategies for sustainable utilisation. Field observations, controlled desert experiments and expeditionary surveys clarified how topography, groundwater depth and climatic variables influence species performance, thereby guiding recommendations for optimal site selection and cultivation. Comparative analysis showed species-specific correlations between productivity and fruit-quality indicators. Particular attention was paid to conserving the gene pool of the Caucasian persimmon (*D. lotus* L.), recognised for its rich biochemical profile and pharmacological potential. Network-pharmacology screening predicted bioactive compounds and therapeutic targets, with a focus on antidiabetic mechanisms. Statistical evaluation employed dispersion tests (F-Fisher) and discriminant analyses (χ^2, Pearson) conducted in Microsoft Excel 2003.

Keywords: *Diospyros L., biogeography, bioecology, biodiversity, gene-pool conservation, bioactive compounds.*

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1. Introduction

The soil and climatic conditions of the Lankaran-Astara region are highly favorable for the cultivation of persimmon species belonging to the genus *Diospyros* L. Each species - *Diospyros kaki* (Oriental persimmon), *Diospyros lotus* (Caucasian persimmon) and *Diospyros virginiana* (American persimmon) - exhibits general biological features along with specific ecological requirements. The natural environment of the Lankaran-Astara region largely satisfies these requirements, supporting both the distribution of these species and the production of high-quality yields. Located in the southeastern part of the Republic of Azerbaijan, the Lankaran-Astara region lies between 38°24′ to 39°24′ north latitude and 47°58′ to 48°58′ east longitude. It is bordered by the Mugan plain to the north, the Iranian state border to the northwest and south and the Caspian Sea to the east. The region's diverse topography, fertile soils and favorable climate create optimal conditions for subtropical agriculture. Persimmon trees, traditionally cultivated in temperate and subtropical climates (Acosta *et al*., 2023), are widely grown in Azerbaijan, particularly in the Lankaran zone (Astara, Lankaran, Masalli), as well as in regions such as Goychay, Agdash, Agdam, Ganja, Balakan and Zaqatala. Among these, *Diospyros kaki* is the most widely cultivated and is recognized as an ecologically clean and nutritionally rich fruit. Its composition includes simple sugars (glucose and fructose), vitamins (B1, B6, B11, PP, C, etc.), phenolic compounds (catechins, leucoanthocyanins, biflavonoids), nitrogenous substances (amino acids, peptides, alkaloids), carotenoids and a variety of macro- and microelements (iron, copper, iodine, bromine, potassium, magnesium, calcium, manganese) (Bakhshaliyev, 2023). The growing global demand for food highlights the importance of plant resources in human nutrition. Plants remain a vital source of carbohydrates, proteins, oils and biologically active compounds. However, changes in natural vegetation - such as deforestation and the loss of native plant species - necessitate detailed studies of species important for food security. In Azerbaijan, studies have identified around 1,500 medicinal plants, 825 essential oil-bearing species, 605 alkaloid-containing plants, 1,500 dye plants, 200 rubber-producing plants, 400 vitamin-rich species, nearly 400 vaccine-related plants, over 800 forage species and more than 600 nectar-bearing plants, including 400 honey plants.

Humans in five main sectors use plants: As food sources;

- As industrial raw materials;
- In medicine;
- For decorative landscaping;
- For environmental restoration and conservation.

Given this, the research aims to examine the bioecological characteristics of persimmon species in different regions of Azerbaijan. It also seeks to identify areas where biochemically rich and medicinally valuable species are concentrated and to determine the most effective methods for their cultivation and conservation. The study outlines the following specific objectives: To determine the geographic locations and coordinates of persimmon varieties and forms distributed across Azerbaijan; To explore the utilization potential of species with high biochemical and pharmacological value; To identify stable forms resistant to biotic and abiotic stress factors; To assess traditional and modern approaches for preserving the gene pool of persimmon species; To classify environmental factors that affect persimmon productivity based on their mechanisms of influence.

Persimmon species are distributed across several economic regions of Azerbaijan, including the administrative districts of Lankaran (Lankaran, Astara, Masalli), Sheki (Zagatala), Goychay-Dashkasan, Gazakh-Tovuz, Mountainous Shirvan and Central Aran. Each region presents unique natural conditions - relief, soil types and climate - which affect the growth and yield of these species.

The Lankaran natural zone is subdivided into mountainous and coastal plains. The mountainous areas are composed of various ridges, while the plains consist of regressive-accumulative marine terraces with negative altitudes. The hydrological system is well-developed, with over 20 major rivers and numerous smaller streams. Seasonal variations in water flow influence the vegetation, contributing to the presence of endemic and relic species. Mountain forests above 350-400 meters above sea level are particularly rich in floristic diversity. Successful cultivation of persimmon in this region depends on understanding its specific ecological requirements. Critical factors affecting yield include temperature, light, humidity, precipitation and wind. These influence key physiological processes such as photosynthesis, respiration and growth. In Lankaran-Astara, the period from December to February is most crucial for persimmon development due to temperature sensitivity. While the species show relative frost resistance, flowering requires temperatures of 18-20°C and early fruit growth needs 18-22°C. Even during hot summers, temperatures reaching 40°C are not harmful if soil moisture is adequate. However, the plant is sensitive to direct sunlight, which can damage chloroplasts. Although persimmon is not highly demanding in terms of soil, it performs best in well-drained, fertile, loamy and humus-rich soils. Waterlogged, clay-heavy or compact soils reduce root vitality and stress tolerance. Irrigated sandy and gravelly soils are especially suitable due to ease of moisture regulation and fertilization. Moisture - both in soil and air - is crucial. Drought stress reduces flowering and fruit quality, while untimely heavy rains, common in autumn and early summer, can negatively affect plant hardening and winter survival.

The Sheki economic region spans 8,960 km^2, representing 10.3% of the country's territory. Its terrain includes high mountains and foothills, leading to a diversity of microclimates favorable for persimmon cultivation. Despite limited land availability, its agricultural sector - especially the food industry - makes up more than 95% of regional industrial output, driven by horticulture, tobacco and livestock production (Pashayev & Aghakishiyeva, 2015).

The Ganja-Dashkasan economic region includes Dashkasan, Goranboy, Goygol, Samukh and the cities of Ganja and Naftalan, covering 5,808 km^2. It is one of the country's key areas for potatoes, grains, viticulture, horticulture and animal husbandry. The Gazakh-Tovuz region, comprising Aghstafa, Gadabay, Gazakh, Shamkir and Tovuz, is bordered by Georgia to the north, Armenia to the west and the Ganja-Dashkasan region to the east. Its diverse terrain - ranging from lowlands to high mountains - supports a range of agricultural activities, including the cultivation of persimmon species (Mammadov *et al*., 2016).

2. Research Object and Methodology

Proper site selection is crucial for the natural adaptation of date palm species in Azerbaijan. The survival rate, growth, longevity, productivity and fruit quality of the trees largely depend on the chosen cultivation site. Therefore, careful study of the soil's relief and groundwater depth is necessary. Flat areas or slopes with a 6-8-degree incline are most suitable. Different date palm species adapt to the environment in different ways. For example, the Oriental persimmon (*Diospyros kaki*) is heat loving and grows best on south-, southeast- or southwest-facing slopes with prevailing winds. Date palms do not thrive in gravelly, sandy, swampy or shallow soils with high groundwater levels - they grow poorly and may dry out. For successful cultivation, the soil must be deep, structured, rich in nutrients, moist and permeable. Irrigated areas are preferred for orchard planting. A commission consisting of an agronomist, soil scientist, land surveyor and farm manager is responsible for selecting the orchard site. Once the site is chosen, a detailed action plan is developed based on the farm's long-term development goals. The plan includes soil preparation, orchard size, variety selection and pollinator layout. Before planting, the land is cleared of trees, shrubs and stones and uneven areas are leveled using machinery. The land is then plowed to a depth of 50-60 cm. If planting occurs in summer, plowing is done the previous autumn; if in autumn and then plowing is done in the previous spring (usually July). Soil analysis is performed and fertilizers are applied accordingly. In structured, fertile soils, 30-40 tons of manure, 60 kg of phosphorus and up to 150 kg of potassium fertilizer per hectare are applied before plowing. In unstructured soils, preparation starts

2-3 years in advance. Before plowing, 600 kg of superphosphate and 150 kg of potassium are applied per hectare. After planting in autumn or summer, fields are leveled, ridged and sown with grass or legumes. Before planting, two rounds of ridging are done and planting holes are prepared. The entire area is mapped to show the irrigation network, orchard blocks, access roads and variety layout. Most fruit trees require cross-pollination for high yields and quality fruit. About 15% of pollinator trees per hectare are enough. Pollinators are planted in a checkerboard pattern, avoiding overlap, with one tree every 2-3 rows. It is best not to plant more than 2-3 varieties in one plot, as this complicates orchard management. Date palms are planted in autumn (November-December) or spring (March-April), depending on the weather. Before planting, seedlings are inspected and weak ones are removed. In subtropical regions, strong varieties are planted at 7×7 or 7×6 meters, while medium and weak varieties at 6×6 or 5×5 meters. To prevent root drying, roots are covered with moist soil or mulch and dipped in a peat-ash solution (1:1 ratio) before planting. To align the rows, a planting board is used. A central stake is placed and the board is aligned using outer stakes. The planting hole is then dug where the center notch marks the location. The root collar should be at soil level - 3 cm above the surface in heavy soils and 5 cm in loamy soils.

Each seedling receives 10-15 kg of compost, 300 kg of superphosphate and 60 kg of potassium chloride mixed into the soil. The soil is gently packed and seedlings are tied to stakes in a figure-eight shape. After planting, the seedlings are recorded and watered immediately.

In studying the role of *Diospyros lotus* L. in the region's biodiversity, various forms were identified based on morphological, biological and agronomic traits. The Lankaran-Astara region - with its mild climate, abundant rain and sunshine and humid air - supports this species in diverse ecosystems. It grows mainly in mixed forests alongside oak (*Quercus*), ironwood (*Parrotia persica*) and hornbeam (*Carpinus*), up to 1500 m above sea level. The species is light-loving. In shaded areas, its crown becomes elongated and sparse, reducing fruit production. It sheds its leaves in winter. Studies show *Diospyros lotus* L. thrives best in ironwood and hornbeam forests, with better fruit yield and quality. It flowers in May-June. The fruits are small (1-2 cm), elongated and conical, ripening in October-November. They can be consumed fresh or dried. The tree can bear fruit without pollination (parthenocarpy).

The rich biochemical makeup and pharmacological value of *Diospyros lotus* L. require both traditional and modern conservation approaches. Traditional methods include seed banks (ex situ) and protected reserves (in situ). Modern conservation uses genetic banks in three categories: Basic collection - for long-term storage, minimal interference, Active collection - for medium-term storage and research, Duplicate collection - stored separately as a backup. Young seedlings grown in protected, monitored areas can be reintroduced into forests to preserve this rare species. Studying the plant's bioecological features allows for improved short- and long-term conservation strategies and sustainable use of its gene pool. Some challenges arise with active collections, such as growing seedlings from diverse environments in a single location, potential genotype mixing through cross-pollination and the long-term maintenance needs of both soil and plants (Bakhshaliyeva, 2023).

Research methodology (Desert Research, laboratory work, fieldwork): To study the place of species belonging to the *Diospyros* genus in the region's flora, monitoring activities were carried out, including desert experiments, field expeditions and observations. These efforts focused on the species' bioecological features, productivity and the chemical composition of their fruits. Biochemical analyses were conducted to help protect and ensure the sustainable use of their gene pool through active collections. Various methods were used to study the chemical composition of the fruits. The content of vitamin C and other vitamins was determined using the Tillmans method, known for its specificity and accuracy. In addition, the iodometric method was applied. Vitamin K content was measured using a spectral method, which is sensitive to ultraviolet wavelengths - 243, 249, 261, 270 and 325 nm for K_1; 243, 249, 260, 270 and 325 nm for K_2 and 244, 253, 263 and 325 nm for K_3. Vitamin K rapidly degrades at these maxima. Fieldwork carried out during desert expeditions from 2019 to 2022 was based on observations and materials collected during these periods. The species *Diospyros lotus* L., from the Ebenaceae family, was studied in detail, particularly its role in local biodiversity. Based on morphological, biological and agronomic indicators, various forms of the species were identified across different populations.

The favorable climate of the Lankaran-Astara region - characterized by mild weather, frequent rainfall, sunny days and humid air - supports the spread of *Diospyros lotus* in multiple ecosystems. The species is mainly found in mixed forests, often alongside oak (*Quercus*), ironwood (*Parrotia persica*) and hornbeam (*Carpinus*), at altitudes ranging from sea level up to 1500 meters. Under suitable conditions, the trees can grow 15-20 meters tall and up to 30 meters in forests, usually with a straight trunk. This is a light-loving plant: in shaded areas, the crown stretches, the canopy thins, fruit drop increases and productivity declines. The tree is deciduous and loses its leaves in winter (Huseynov & Bakhshaliyeva, 2023). To preserve the gene pool of the Caucasian persimmon (*Diospyros lotus* L.), both traditional and modern methods have been used. Traditional methods include collecting specimens, creating a seed bank (*ex situ*) and establishing reserves and protected areas (*in situ*). Modern approaches focus on forming genetic banks structured into three types of collections:

1. **Basic (initial/base)** - for long-term conservation with minimal intervention.
2. **Active** - for medium-term use, including recovery, propagation and study.
3. **Additional (duplicate)** - kept separately to ensure secure conservation (Pashayev & Aghakishiyeva, 2015).

It has been found that young seedlings of *Diospyros lotus*, grown in specially protected areas and under constant monitoring, can be successfully reintroduced into natural forest ecosystems. After detailed studies of the biological and ecological features of this species across the Republic, short- and long-term strategies for conservation and sustainable use can be applied to fully preserve its genetic diversity. However, several challenges emerged during the maintenance of active collections. For example: Seedlings from different ecological areas were grown in a single environment, which affected their adaptability. Cross-pollination in protected collections compromised genotype purity. Maintaining certain soil types and plant varieties required continuous care. Collections were vulnerable to diseases and pests, which could reduce biological productivity.

To protect the gene pool, both natural and artificial conservation areas are necessary. These include nature reserves, national and dendrological parks, arboretums, wildlife sanctuaries, botanical gardens, seed plantations and the establishment of seed and clonal archives. In this respect, the goals of forest genetics and selection align closely with broader conservation objectives. Expeditions conducted from 2019 to 2022 revealed the existence of diverse forms of *Diospyros lotus* L. across various populations, based on their morphological, biological and agronomic characteristics. The creation of such diversity is mainly due to the mild climate of the Lankaran-Astara region, abundant rainfall, sunny weather, humid air and fertile soils. Notably, in higher mountainous areas, the intensity of flowering in *Diospyros lotus* decreases as altitude increases, likely due to changes in temperature and soil mineral content.

Ecological Research *(Climate and Soil Conditions):* In Azerbaijan, both soil and vegetation types vary with altitude above sea level. Several factors influence changes in soil quality, including topography, climate, soil age, characteristics of the parent material, vegetation cover, soil organisms and human activity. The Nakhchivan Autonomous Republic has a sharply continental climate. Forest zones in this region are very limited or nearly absent. As a result, soil zonation is also weak or virtually nonexistent.

In contrast, the Lankaran region shows clear differences in soil types between mountainous and lowland areas. For example, at elevations of 1600-1800 meters above sea level, mountain meadow soils are found. Further down the slopes, brown and yellow soils predominate. These differences are mainly due to the region's varied relief. As noted earlier, temperature affects both soil quality and color. In Azerbaijan's mountainous areas - especially on southern slopes - soils tend to be weak, low in humus, stony and dry. However, on northern slopes, soils are richer in humus and receive less direct sunlight. In colder regions, soil color tends to be darker due to higher organic matter content.The studied species *Diospyros lotus* L. (commonly known as Caucasian date plum) has spread in mountain gray and mountain forest soils. These soil types are typically found in the mountains and foothills of the Talysh region at altitudes of approximately 700-1200 meters above sea level. In the Talysh region, the distribution area of *Diospyros lotus* L. is among the smallest for plant species. Historically, forests of this species covered larger areas. However, due to human activities - such as cutting the trees for carpentry and other purposes - the distribution area has significantly shrunk.

One practice that has especially contributed to this decline is the cutting of branches to make fruit harvesting easier. These interventions have led to the species becoming rare. Similarly, the chestnut tree, another rare and valuable species known for its strong, colorful and durable wood, was once widespread in the Talysh region but now occupies only a small area (Mammadov *et al*., 2016). Soil and climatic conditions in Azerbaijan directly affect the ecological adaptability of *Diospyros lotus* and related species. Recent studies show that climate change has altered rainfall patterns and increased the salinity of irrigation water (Gil-Muñoz *et al*., 2020).

Figure 1. Oriental Persimmon, *(Diaspyros Kaki)*

Soil salinization or a tendency toward it, negatively impacts plant quality indicators. Generally, there are two primary strategies for addressing soil salinization: improving irrigation and drainage systems or enhancing plant resistance to salinity. According to Arzani and Ashraf (2016), restoring saline soils is often challenging. Thus, the most effective and widely adopted solution is the use of salt-tolerant varieties (Gil-Muñoz *et al*., 2020; Arzani *et al*., 2016). In the case of woody plants, the best approach is to use rootstocks that are resistant to salinity (Forner-Giner e*t al*., 2013). The *Diospyros* genus includes three species commonly used as rootstocks: *Diospyros kaki*, *Diospyros lotus* and *Diospyros virginiana* (Gil-Muñoz *et al*., 2020; Badenes *et al*., 2015).

As seen in Figure 1, the Oriental Persimmon (*Diospyros kaki*) is a fruit tree native to the Far East and it goes through several development stages. The life cycle of the persimmon tree begins when the seed falls into the soil and starts to germinate. Seeds planted in autumn usually sprout under suitable conditions. As the seedling develops, it forms a root system and grows toward the soil surface. At this stage, seedlings are typically weak and delicate, requiring regular care. When the seedlings reach a certain size, they grow into young trees. At this point, the trees become stronger, with more developed roots and branches. In spring, young trees start to flower. Their branches are covered with white or yellow flowers. After pollination, the flowers turn into small green fruits. During this period, the trees supply nutrients to the fruits, supporting their growth. In summer, the fruits begin to grow and ripen. Their color changes and the texture become softer. Ripe fruits are harvested in autumn. They are picked by hand and prepared for processing. The harvested fruits are packed and distributed for sale in markets. During winter, persimmon trees enter a dormant phase. In this period, they store energy for the next growing season. Each of these stages plays a vital role in the persimmon tree's life cycle, ensuring healthy growth and fruit production. The next variety is the Caucasian Persimmon (*Diospyros lotus L.*), whose full development stages are shown below in photo chronics.

Figure 2. Caucasian Persimmon (*Diaspyros lotus* L.)

As you can see from Figure 2, like other persimmon varieties, Caucasian Persimmon (*Diospyros lotus* L.) is a fruit tree native to the Caucasus region and its life cycle includes several stages. Persimmon seeds are usually sown in the ground in autumn. Seedlings develop root systems underground and begin forming stems and leaves above ground. Once the seedling reaches a certain size, it becomes a young tree. At this stage, the tree strengthens its branches and roots. In spring, young persimmon trees start to bloom. Flowers are pollinated by bees or the wind. Fertilized flowers gradually turn into small green fruits. During summer, the fruits grow, ripen, change color and develop their characteristic flavor.

Common Persimmon (*Diospyros virginiana*) also follows a similar life cycle. A photo chronicle of this variety is provided, showing the development stages of the fruit.

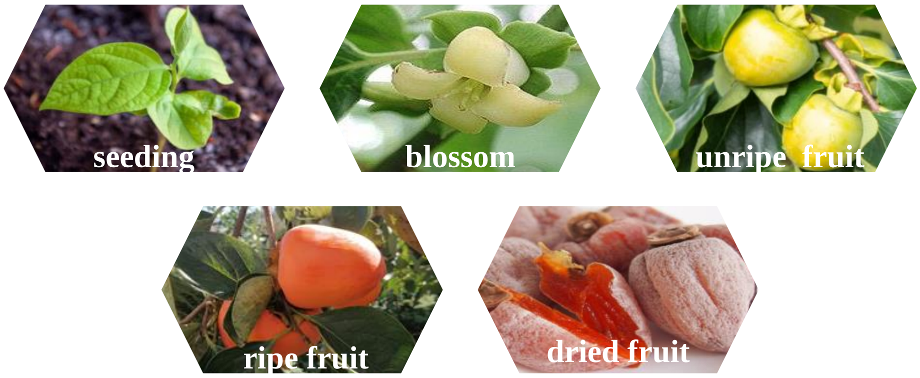

Figure 3. Common Persimmon *(Diaspyros Virginiana)*

According to Figure 3, there are both similarities and differences between the persimmon varieties. The Common Persimmon (*Diospyros virginiana*), which originates from the American New World, is widely grown in Azerbaijan, especially in subtropical climate zones. This fruit tree is known for its sweet fruits and is often consumed fresh or used in making jams, marmalades and syrups. In Azerbaijan, the Common Persimmon is commonly found in home gardens and commercial orchards and is considered a valuable fruit by local people. Additionally, its leaves are sometimes used in traditional medicine and have cultural significance. Diospyros lotus is the most commonly used rootstock in the Aral Sea region due to its tolerance to saline soils, adaptability and lack of basal shoots. However, it is highly sensitive to waterlogging (Gil-Muñoz *et al*., 2020; de Paz *et al*., 2016). Diospyros virginiana is also tolerant to salinity and performs well in saline soils. Diospyros kaki is the most widely used rootstock species worldwide, as its varieties adapt quickly to changing environmental conditions. One additional challenge in cultivating persimmon species is selecting the right initial plant material. New methods have been developed for some genotypes of *D. lotus*, while *D. virginiana* has shown a quicker adaptation to changing conditions (Giordani *et al*., 2012). In terms of salt stress, *D. virginiana* is relatively tolerant, while *D. lotus* and *D. kaki* are more sensitive (Gil-Muñoz *et al*., 2020; de Paz *et al*., 2016). However, within each species, there is little diversity in salt tolerance.

Natural Habitats (Biological Characteristics of Persimmon Species in Different Habitats):

The normal growth and productivity of persimmon plants strongly depend on the chemical composition of the soil. Nitrogen (N) is the most important nutrient for vegetative growth and is essential for plant physiological processes. A lack of nitrogen causes stunted growth and yellowing of leaves. Phosphorus (P) is vital for root, flower and fruit development, as it is involved in the synthesis of nucleic acids, phospholipids and sugar phosphates (Bondada & Oosterhuis, 2001; Raghothama & Karthikeyan, 2005). Potassium (K) plays a key role in productivity, aiding fermentation reactions, osmotic balance and water regulation (George *et al.*, 2005). Calcium (Ca), a secondary macronutrient, promotes root development and helps in nutrient and water uptake. Its deficiency is first seen in young leaves, which show deformation and chlorosis. Magnesium (Mg) is a crucial component of chlorophyll and is involved in the synthesis of carotenoids and xanthophylls. A deficiency in magnesium typically causes chlorosis along leaf margins. Micronutrients like iron (Fe), manganese (Mn) and boron (B) are essential for various enzymatic and metabolic functions and also contribute to chlorophyll production (Dong *et al*., 2010). The biochemical composition of persimmon leaves also affects the plant's biological traits. Vis-NIR reflectance spectroscopy is a promising method for assessing macro- and micronutrient levels in leaves throughout the growing season. Spectral reflectance data in the 430-1040 nm range provided satisfactory prediction results for N, P, Ca, Mn and B concentrations, with determination coefficients above 0.70. However, the results for K, Mg and Fe were less reliable. Still, the RMSEP (Root Mean Square Error of Prediction) values were low, suggesting high accuracy. More research is needed to determine if these models, based on a single year of data, will be consistent in future years (Dasy & Avasthe, 2018). A cladogram and principal component analysis show a correlation between genetic characteristics and fruit quality traits, suggesting that both genetic and pomological classification is important. This supports the need to identify promising genotypes for germplasm conservation and future breeding programs (Martinez-Calvo *et al*., 2013).

Potential Medicinal Composition (Active Chemical Compounds)

Plants are among the richest sources of bioactive compounds. Plant materials exhibit a wide range of biological activities and play a crucial role in maintaining human health and treating diseases (Cho *et al*., 2017; Adams & Wang, 2015). In traditional Chinese medicine, the use of various plant species has often produced results that Western medicine could not achieve (Loizzo *et al*., 2009; Faiz & Polyphenol, 2017). Diospyros lotus L. is known for its special selectivity (Nabavia *et al*., 2009). It is a tree species from the widespread *Diospyros* genus, belonging to the Ebenaceae family in China. While cultivated for its edible fruits, it is also used in traditional medicine in several countries (Arnal *et al*., 2004; Glew *et al*., 2005). This species has economic value due to its rich biochemical composition and high-quality timber. Its wood remains prized for furniture and other timber products. In China, the leaves are used traditionally to treat stroke and apoplexy syndrome. In Japan, they are used as a hypotensive remedy (Fan & He, 2006). In Korea, the plant is used in herbal teas and in managing hypertension (Lee *et al*., 2009; 2015). The main chemical components of *Diospyros lotus* leaf extracts include alcohols, acids, phenols, ethers and aromatic compounds. These substances exhibit antibacterial, anti-inflammatory, antitumor and antioxidant activities. As a result, they can be used in medicine, food products and skincare. Additionally, leaf extracts are directly used in traditional Chinese medicine (Yang, 2020).

As is well known, iodine (I) is one of the most important trace elements for the human body. According to the World Health Organization (WHO), around 1.5 billion people globally suffer from iodine deficiency. This condition can lead to the enlargement of the thyroid gland and the development of goiter. Currently, approximately 300 million people worldwide are affected by thyroid-related illnesses. People aged 12 and older are recommended to consume 150 micrograms (μg) of iodine daily. The Sheki-Zagatala region in Azerbaijan is identified as a hotspot for iodine deficiency. Our research has shown that the East Persimmon (*Diospyros kaki*) grown in this region contains 0.002% iodine. In addition to other preventive measures, it is important for residents of the Sheki-Zagatala region to include East Persimmon fruits and related products in their diet, as these fruits contain a notable amount of iodine (Bakhshaliyeva, 2023; Delange *et al*., 1997). Later, our team used the Sonoscape S9 Pro portable ultrasound device equipped with a 15 MHz linear transducer for further analysis. For statistical evaluation, we used dispersion analysis (Fisher), discriminant analysis (χ^2, Pearson's measure) and Microsoft Excel 2003 (Microsoft Corporation). The most reliable method to assess the presence and severity of iodine deficiency is through measuring urinary iodine levels. For this reason, we recommend collecting morning urine samples from students in sealed, labeled plastic containers. The WHO recommends several methods for assessing iodine deficiency. Among them, thyroid gland palpation is widely used, especially in epidemiological studies. So far, no national map of iodine levels in Azerbaijan has been created. The iodine content in the country's underground water sources ranges from 0.49 to 146.4 µg/L, while in surface waters, it ranges from 0.49 to 55.78 µg/L. Several studies have assessed goiter occurrence in different regions and age groups.

During thyroid palpation exams, grade I goiter was found in 3 students (1.5%), while grade II goiter was not observed. There was no significant difference in goiter prevalence between boys and girls. Urinary iodine analysis was conducted for 189 students (Table 2), while 82 students did not provide samples. The assessment revealed: Severe deficiency in 12.2% of cases: Qabala: 15.4%, Quba: 21.1%, Sheki: 1.5%

Moderate deficiency in 21.2%: Qabala: 10.8%, Quba: 42.1%, Sheki: 13.4%

Normal iodine levels in 49.7% overall: Qabala: 52.3%, Quba: 29.8%, Sheki: 64.2%

Iodine excess in 16.9%: Qabala: 21.5%, Quba: 7%, Sheki: 20.9%

Table 1. Iodine Concentration in Urine

Iodine in urine	Gabala	Guba	Sheki	Sum
Acute deficiency, < 70 mkg/L	10 (15,4%)	12 (21,1%)	1 (1,5%)	23 (12,2%)
Mild deficiency, 70-99 mkg/L	7 (10,8%)	24 (42,1%)	9 (13,4%)	40 (21,2%)
Norm, 100-300 mkg/L	34 (52,3%)	17 (29,8%)	43 (64,2%)	94 (49,7%)
Surplus, ≥300 mkg/L	14 (21,5%)	4 (7,0%)	14 (20,9%)	32 (16,9%)
Total	65 (100%)	57 (100%)	67 (100%)	189 (100%)

Severe iodine deficiency was 9-11 times more common in Quba and Qabala schools compared to Sheki. Based on WHO/UNICEF/ICCIDD criteria, 63 students (33.4%) had severe or moderate iodine deficiency, of which 43 were girls (68.3%) and 20 were boys (31.7%) (Bakhshaliyeva, 2023; Hummatov *et al*., 2018).

Currently, *Diospyros lotus* L. shows potential for use in the treatment of diabetes. However, its chemical composition and pharmacological properties need to be fully understood before it can be widely applied for this purpose.

Recent research has used network pharmacology analysis to explore the potential bioactive compounds in *Diospyros lotus* L. and their mechanisms of action. This approach included screening for key quality markers and predicting as well as functionally enriching target genes related to diabetes treatment. The study identified 159 compounds in *Diospyros lotus* L., with 140 reported for the first time. Through the network pharmacology analysis, 40 active components were highlighted as potentially effective against diabetes. These include quercetin, luteolin and kaempferol, among others. These findings suggest that *Diospyros lotus* L. contains several bioactive compounds that could be useful in managing diabetes and shed light on the plant's possible molecular mechanisms in treatment (Shihan *et al*., 2022). Additionally, the fruit extract of *Diospyros lotus* L. has demonstrated antidiabetic, antitumor, antinociceptive and anti-inflammatory effects. It is traditionally used to treat hypertension, diarrhea and dry cough (Uddin *et al*., 2014; Cho, 2016).

Medical Applications (Impact of Research on Medical Fields and Potential Medical Uses)

In folk medicine, the fruits of *Diospyros kaki*, also known as persimmon, have been traditionally extracted into spirits and used to treat various conditions. These include enlarged spleen-like disorders, general weakness, nervous system issues, loss of appetite and high blood pressure. They are also used as expectorants for bronchitis and other respiratory diseases and as anti-inflammatory agents. Due to the iodine (I) content in its fruit, *Diospyros kaki* grown in the Sheki-Zagatala region is considered one of the most iodine-rich plants in the area (Bakhshaliyeva, 2023). Preparations made from the rich biochemical compounds in date palm fruits are used in the treatment of different types of diabetes. The global prevalence of Type 2 diabetes has steadily increased and is expected to pose a serious economic burden on healthcare systems (Kaiser *et al*., 2018). Type 2 diabetes is a chronic condition where blood sugar levels rise due to insulin resistance, eventually leading to reduced insulin production. A sedentary lifestyle and high-calorie diet are major contributing factors (Bradley & Hsueh, 2016). Functional foods are being explored as a preventive and therapeutic option for lifestyle-related diseases, including diabetes. These foods not only help manage diseases but may also prevent their onset in high-risk individuals, potentially reducing reliance on medication (Arihara *et al*., 2004; Alkhatib *et al*., 2017). Recent research has identified *Diospyros lotus* L. fruit as a natural starch hydrolysis inhibitor, making it a promising candidate for diabetes management. This effect is linked to its action on amylase and to a lesser extent, alpha-glucosidase. Among its phenolic compounds, quercetin and myricetin are the most potent inhibitors. Amylase plays a key role in the initial stage of starch digestion and affects postprandial blood glucose levels. Although intestinal alpha-glucosidases are weaker, they are still physiologically significant (Krentz *et al*., 2005; de Sales, 2017). These properties make *Diospyros lotus* L. a valuable multi-component functional food, with the potential to help prevent or manage diabetes. Further studies may support its use as a food additive with health and economic benefits (Koekemoer *et al*., 2021). *Diospyros lotus* L. is also known for its drought resistance and hardiness, making it similar to date palm trees in terms of environmental adaptability (Yang *et al*., 2014). Its fruits are used to treat kidney stones, cancer and bacterial infections (Rauf *et al*., 2015). Modern research has focused on its phylogenetics, genetic resistance, nutrition and medicinal properties (Koekemoer *et al*., 2021). Although propagation through seeds is common, it often results in genetically diverse plants. Genetic transformation helps reduce development time and stabilize traits, but requires an efficient seed development system (Li *et al*., 2018). Oxidative stress, caused by an imbalance between free radicals and antioxidants, is a major contributor to chronic diseases. Natural compounds from *Diospyros kaki* leaves, such as flavonoids and triterpenoids, have shown antioxidant properties, protecting against oxidative damage and improving related conditions. These leaves also contain phenylpropanoids, alkaloids, phenolic acids and terpenes, which have been linked to antioxidant and neuroprotective activities. Studies indicate that flavonoids and leaf extracts from *Diospyros kaki* can activate oxidative stress responses and mitochondrial apoptosis, inhibit the growth of human prostate cancer cells and trigger other mechanisms leading to cell death. Research has also demonstrated the plant's potential in inhibiting the proliferation of human colorectal adenocarcinoma (CaCo-2), ovarian sarcoma (Skov-3) and dermal fibroblast (HDF) cancer cells (Keskin *et al.*, 2023).

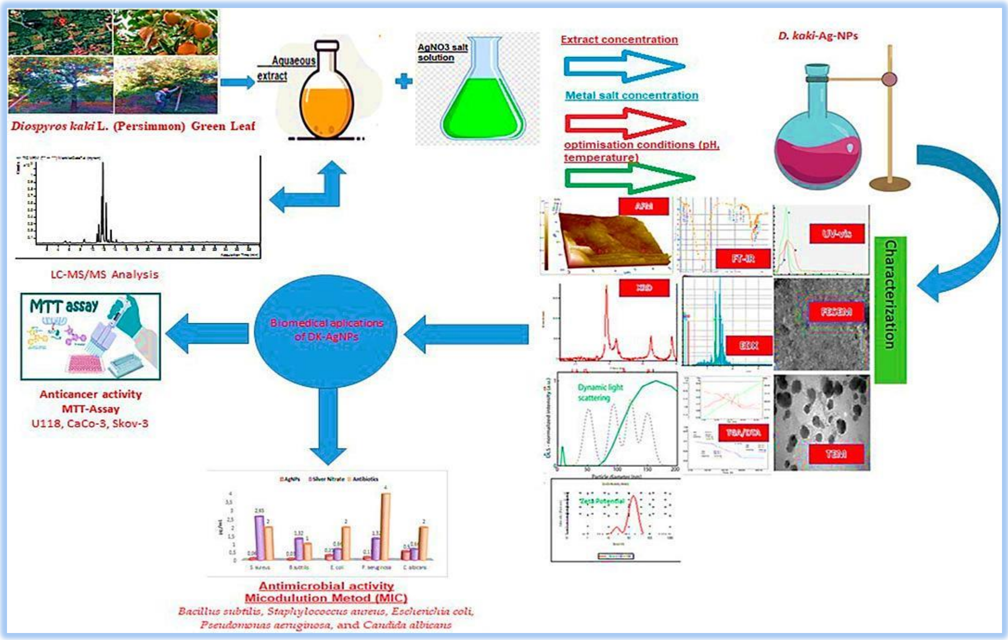

Figure 4. Schematic description of the biomedical applications of *Diospyros kaki's* leaf Aqueous extract
Source: Keskin et al. (2023)

The main chemical compounds that regulate oxidative stress in *Diospyros kaki* leaves are polyhydroxylated compounds. These natural products show strong antioxidant activity. Regulating oxidative stress is essential in using *Diospyros kaki* leaves to treat human diseases. This summary outlines the main structural types of natural compounds found in the leaves and highlights their potential roles in neuroprotection, diabetes management, kidney protection, retinal degenerative diseases and cancer-related oxidative stress. The chemical composition and pharmacological effects of *Diospyros kaki* leaves have been broadly reviewed. The link between their chemical constituents and pharmacological activities is particularly important in the context of oxidative stress. This research contributes to the development of natural antioxidant drugs (Hong *et al*., 2024). As a beneficial natural product, date palm leaves have long supported human health. In China, they have been used in traditional medicine since ancient times. Their first recorded use appeared in the Ming Dynasty's *Diannan Bencao*, where a paste made from the leaves was applied to treat eczema (Deng *et al*., 2012). Date palm leaves have also been used to treat cough, asthma, hypertension, stroke and other diseases (Lu & Li, 2016). Additionally, leaf tea has been consumed as a natural food supplement in Japan, South Korea, China and other Asian countries (Tsurunaga *et al*., 2011). Date palm leaves are now widely used in health and medical products, including cosmetics and clinical treatments such as Naoxinqing (Hanamura *et al*., 2008; Guo *et al*., 2021). Despite their long history of use, these leaves still offer untapped potential for promoting well-being. Experimental studies show that date palm leaf extracts help protect the skin from harmful ultraviolet radiation (Cho *et al*., 2017). They have also shown therapeutic benefits in treating atopic dermatitis (Cho *et al*., 2017).

Plant Adaptation and Biological Characteristics Anatomical Research (The importance of anatomical structures of date palm plants for bioecology and adaptation): Date palm species show differences in their anatomical structures depending on the ecological conditions of the regions where they grow. These anatomical features affect the plants' bioecology and their ability to adapt to different environments. Vegetation on Earth has a long history and is constantly changing under the influence of external factors. Each plant species draws energy and necessary resources from the environment in which it lives and is influenced by both biotic (living) and abiotic (non-living) factors. Studying the classification, development, distribution and ecological relationships of plants is essential. In this context, research on rare and endangered tree and shrub species of Azerbaijani flora is especially important for preserving biodiversity. *Diospyros lotus* L. **-** the Caucasian persimmon - is a deciduous tree that can grow up to 15 meters tall in natural conditions. Its leaves are elliptical, with smooth or slightly serrated edges. The upper surface of the leaves is dark green and smooth, while the lower surface is also dark green but slightly hairy, though the hairs fall off over time. The bark on the trunk is thick, dark and deeply cracked. Young shoots are greenish-brown or dark reddish-brown. The leaves are arranged alternately on the branches. The plant is dioecious, meaning male and female flowers grow on separate trees. Female flowers are solitary, while male flowers are found in the leaf axils. In its natural habitat, the species grows more frequently on moist mountain slopes, along rivers and near springs. It is typically found at elevations between 400 and 800 meters above sea level. In Azerbaijan, *Diospyros lotus* is found in the regions of Lankaran, Lerik, Astara, Zagatala, Ismayilli, Balaken, Yardimli and Masalli. Outside Azerbaijan, it is distributed across Georgia, Central Asia and countries around the Aral Sea, Iran, India, China and Japan. In Azerbaijan, it is considered a rare and relict species.

Reproductive Research (Plant reproduction mechanisms and their importance): The Caucasian persimmon - *Diospyros Lotus L.* - is a widely distributed species. It grows wild in Japan, China, Afghanistan, Iran, Turkey and the Caspian Sea region. This species is found in the Caucasus and Caspian areas, from sea level up to 1500 meters in mountainous and foothill zones. In the wild, it grows in Azerbaijan, Georgia and the North Caucasus. Studies have shown that Azerbaijan, especially the Lankaran-Astara zone, is the main center of intensive growth for this species in the country. Depending on the growing conditions, the Caucasian persimmon is a tree with a straight trunk reaching 15-20 meters tall, sometimes up to 30 meters in forests. It sheds its leaves in winter. The plant can be either monoecious (both male and female flowers on the same plant) or dioecious (separate male and female plants). Its flowers are pale yellow-white. Female flowers have one pistil, an ovary located above and a few underdeveloped stamens covered with thin hairs on small waxy bumps. The ovary is ovoid with 4-8 chambers. Male flowers are relatively small. Flowering occurs from May to June. The fruits are small, oval and 1-2 cm long. The plant is capable of parthenocarpic fruiting (fruit formation without fertilization). The plant is mainly dioecious, but some varieties are monoecious. Flowers come in three types - male, female and hermaphroditic. Male flowers are usually clustered or sometimes solitary. They have a narrow bell-shaped corolla covered with short hairs and 4-6 thickly hairy calyx leaves. Each male flower has 16-26 light brown stamens. Female flowers are solitary or sometimes appear in pairs, with 4-6 large hairy calyx leaves and 5 sepals. The ovary is positioned above and has 8-10 chambers, covered with hairs. In monoecious plants, the flowers are hermaphroditic, medium-sized, with 5 sepals, 5 pistils and 22 stamens.

The vegetative phase of the Caucasian persimmon begins in March, although in cold summers it may start later. Root development begins in mid-February. Flowering starts when the average daily temperature reaches +15 to +18°C or higher. Flowers appear on branches. The flowers can be dioecious or polygamous. Usually, fruits form on third and higher order branches. Generative buds typically develop from the third to fourth buds on a branch. The number of generative buds depends on branch length: longer branches have more buds and until a certain length, the number of buds that don't open decreases. On average, each branch has 2-13 generative buds. Fruits form in 2-4 groups on the lower part of the branch. During flowering, about 2500-3500 flowers bloom on a tree. Depending on the variety and conditions, the fruit set rate ranges from 35% to 75% (Mammadov *et al*., 2016). Research has shown that male and female flowers of *Diospyros Lotus L.* differ in shape and size. Morphological analysis revealed a range of traits both within and among plants. There are also significant differences in corolla color. The female and male flowers of different genotypes were grouped based on absolute flower parameters, with five clusters for male flowers and three for female flowers identified. Similarity between groups was measured using Euclidean distance. Principal component analysis grouped flowers into clusters with similar morphological traits (Grygorieva *et al*., 2023). This research expanded the known morphological characteristics of *D. lotus* flowers compared to earlier brief descriptions. Studying variability is one of the best ways to discover a species' adaptability potential when introduced to new environments. It is known that long-term cultivation significantly increases intraspecific diversity over time (Grygorieva *et al*., 2023). Under natural optimal conditions, the species' variability is very limited. Variation in traits across different habitats arises from diverse ecological conditions. Such information helps identify adaptive mechanisms that keep the species viable in certain environments (Grygorieva *et al*., 2023; Mikovski *et al*., 2021). Morphometric studies confirmed variability in the morphological traits of *Diospyros Lotus L.* flowers.

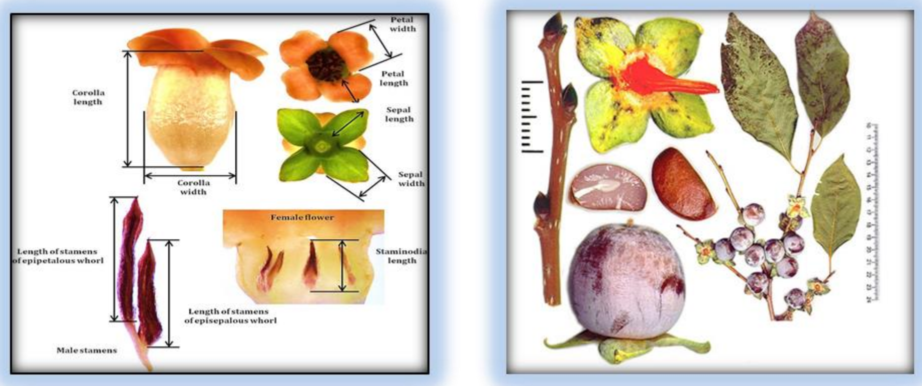

Figure 5. Flowers of *Diospyros Lotus* L. showing the floral characteristics measured
Source: Grygorieva et al. (2023)

3. Results and Discussion

Several important findings were obtained as a result of this research. The main results and conclusions are summarized below: There is a correlation between the genetic characteristics of *Diospyros lotus* L. genotypes and the quality traits of their fruit. The content of microelements such as vanadium (V), tin (Sn), iodine (I), selenium (Se), zinc (Zn) and molybdenum (Mo) in the fruit of *Diospyros kaki* (commonly known as persimmon) was found to be stable across all regions of Azerbaijan where the study was conducted. The iodine (I) level in *Diospyros kaki* fruit grown in the Sheki-Zagatala region remained consistent and accounted for 0.002% of the fruit's composition. By studying the role of the Caucasian persimmon (*Diospyros lotus* L.) in regional biodiversity, it was determined that creating a seed bank and organizing conservation efforts in reserves and protected areas would be beneficial for its preservation and sustainable use.

Importance of the Results, Research Opportunities and Future Work

The Sheki-Zagatala economic region (which includes Balakan, Qakh, Gabala, Oghuz, Zagatala, and Sheki) and the Lankaran economic region (including Jalilabad, Astara, Lerik, Lankaran, Masalli and Yardimli) are considered endemic areas with moderate iodine (I) deficiency. *Diospyros kaki* is widely cultivated in these regions. Therefore, in addition to other health measures, it is recommended that the local population increase consumption of persimmon-based products, which are rich in iodine and other essential microelements. Further research is needed on the genetic diversity of persimmon species found in Azerbaijan through molecular genetic analysis. This approach helps identify genetically stable forms and supports the use of genetically distinct varieties in breeding programs. The use of molecular markers has proven effective in studying genetic variation among persimmon genotypes (Peche *et al*., 2023).

The genetic groupings identified through molecular analysis show a clear link between the genetic traits and fruit quality characteristics. This demonstrates a strong relationship between the genetic origin and pomological traits of persimmon varieties. These findings highlight the importance of characterizing genotypes at both genetic and fruit-quality levels to support germplasm management and genetic improvement efforts (Peche *et al*., 2023).

4. Conclusion

This study provides a comprehensive analysis of the bioecological and biochemical variability of persimmon species (Diospyros L.) across diverse soil and climatic conditions in Azerbaijan. Our results clearly demonstrate that the mineral composition of regional soils significantly influences the elemental profile of persimmon fruits, seeds and vegetative organs. However, this relationship is not straightforward: the biochemical composition is also modulated by the intrinsic genetic differences among varieties and forms of Diospyros, reflecting a complex interaction between genotype and environment. Notably, we observed substantial intraspecific variability driven by natural hybridization and mutations, which lead to the emergence of novel biotypes exhibiting distinct biochemical signatures. This genetic and biochemical diversity presents promising opportunities for breeding programs aimed at developing new persimmon cultivars with enhanced nutritional and medicinal properties tailored to specific agroecological zones. From a practical standpoint, our findings underscore the importance of region-specific cultivation strategies. By aligning persimmon varieties with the unique pedoclimatic conditions of Azerbaijani regions, agricultural practices can be optimized to maximize fruit quality, particularly the accumulation of biologically active compounds such as antioxidants, vitamins and trace elements. Such targeted cultivation not only improves crop yield and fruit nutritional value but also enhances the potential health benefits of persimmon consumption, reinforcing its role in traditional and modern medicine. Looking forward, further research is essential to deepen our understanding of the genetic mechanisms underlying the observed biochemical diversity. Advanced molecular studies should focus on characterizing the genetic structure of newly identified biotypes and elucidating how environmental stressors influence gene expression related to metabolite synthesis. Additionally, biotechnological approaches, including marker-assisted selection and genetic modification, could be explored to develop resilient persimmon varieties with superior fruit quality and adaptability to changing climate conditions. In summary, this research bridges fundamental bioecological knowledge with applied agricultural science, paving the way for innovative cultivation practices and the sustainable use of Diospyros species in Azerbaijan's diverse landscapes.

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