## FROM THE EDITORIAL BOARD

"A country with a clean environment and green growth" is one of the five national priorities for the socio-economic development of Azerbaijan, scheduled to be implemented by 2030. Following this priority, intensive work is being carried out to improve the environment, restore and increase greenery, and ensure the efficient use of land and water resources, and sustainable energy sources. As a continuation of the above activities, 2024 was declared the "Green World Solidarity Year" in the country by the President of the Republic of Azerbaijan.

By the unanimous decision of the world community, the 29th session of the Conference of the Parties to the UN Framework Convention on Climate Change (COP29) was held with great success in the Republic of Azerbaijan on November 11-22, 2024. It was also remembered for very important historical decisions related to science.

Along with other factors, the special role of fundamental and applied science, as well as high technologies, was repeatedly emphasized during COP29 at events attended by relevant international, regional, and national organizations, specialists, and experts. These events focused on addressing global environmental, food, biosecurity, and health issues, as well as combating and mitigating the effects of climate change.

COP29 has once again demonstrated that solving climate-related issues today requires complex scientific and multidisciplinary approaches in defining research directions and planning, and that, along with technological advances for research and innovation, there is a need for effective decision-making and the creation of a favorable environment for research through adequate capacity and technical support.

During the year, international and local scientific conferences, symposiums, seminars, exhibitions, etc. related to the "Green World Solidarity Year" and COP29 were held in the Republic of Azerbaijan, and books, articles, special issues of scientific journals, etc. were published.

There is no doubt that all of this will significantly support the development of Azerbaijani science and education in such areas as ecological restoration, modern study, protection and efficient use of all branches of biodiversity, including at the molecular-genetic level, combating climate change and its consequences, agriculture, food and nutrition security, "green energy", etc.

The Republic of Azerbaijan, with its constantly growing human capital, economic power, scientific and technological potential, will optimally achieve all the established "green" priorities, Sustainable Development Goals related to the environment and biodiversity, and the effective implementation of the commitments, slogans and decisions of COP29 at the national level in the shortest possible time. It will also become a "country of clean environment and green growth."

The aforementioned topics, the "'Green World Solidarity Year," and COP29 are the focus of the current special issue of the Journal of Life Sciences & Biomedicine, one of the leading publications in Azerbaijan on related sciences.

Fourteen scientific research and review articles from Azerbaijan and abroad in relevant scientific fields were selected and included in the special issue of the journal.

**Sincerely,**

**academician Irada Huseynova,**
**Deputy Editor-in-Chief**



https://doi.org/10.59849/2710-4915.2024.2.05
Available online 31 December 2024

*Journal of Life Sciences & Biomedicine, vol. 6(79), No 2, p. 06-12 (2024)*

# Proline accumulation and WRKY14/WRKY36 gene expression dynamics during drought-induced flag leaf senescence

**Turana Isgandarova[1], Samira Rustamova[1], Tofig Allahverdiyev[1,2], Irada Huseynova[1*]**

*[1]Bioadaptation Laboratory, Institute of Molecular Biology & Biotechnologies, Ministry of Science and Education of the Republic of Azerbaijan, AZ1073, Baku, Azerbaijan*
*[2] Department of Plant Physiology, Research Institute of Crop Husbandry, Ministry of Agriculture of the Republic of Azerbaijan, Pirshagi, Sovkhoz-2, AZ1098, Baku, Azerbaijan*

***For correspondence:** i.huseynova@imbb.science.az*

Received: September 1, 2024; Received in revised form: October 17, 2024; Accepted: November 26, 2024

**Wheat is one of the most important cereal crops globally; however, its productivity is often reduced due to abiotic stresses, particularly drought, which accelerates leaf senescence. This study focuses on investigating the roles of proline and WRKY transcription factors, specifically *WRKY14* and *WRKY36*, in regulating drought-induced premature senescence in wheat genotypes with varying stress tolerance. The experiments included genotypes of bread wheat (*Triticum aestivum* L.) and durum wheat (*Triticum durum* Desf.), which were cultivated under controlled conditions with normal and drought regimes. After the booting stage, irrigation was discontinued for the drought-treated plants. Flag leaf samples were collected 7, 14, 21, 28, and 35 days after anthesis. Proline accumulation was significantly higher in drought-tolerant genotypes, peaking 21 days after anthesis, compared to sensitive genotypes. Similarly, the expression of *WRKY14* and *WRKY36* genes showed genotype-specific dynamics. The *WRKY36* gene exhibited higher expression levels in drought-tolerant genotypes, particularly under drought conditions, while the transcriptional activity of *WRKY14* was more associated with senescence processes. Understanding the molecular mechanisms governing proline metabolism and the role of WRKY transcription factors can offer valuable insights for developing wheat varieties with improved resistance to premature senescence.**

***Keywords:*** *Wheat, aging, water deficiency, transcription factors, RT-PCR*

## INTRODUCTION

Wheat is one of the most important cereal crops, meeting the primary dietary needs of the global population and holding strategic significance worldwide (Saeed et al., 2024). Leaf senescence is a key agronomic trait that limits crop productivity (Guo et al., 2021; Gregersen et al., 2013). Senescence is a tightly regulated, complex process with significant implications for plants. Extending the duration of photosynthesis by delaying senescence in leaves during the grain-filling stage has been identified as an important strategy for enhancing both yield and grain quality (Li et al., 2024). This process involves the programmed redistribution of nutrients to developing tissues, replacing cellular functions with programmed cell death to ensure plant survival (Lim et al., 2007). During senescence, macromolecules such as proteins, lipids, and nucleic acids are broken down, and their components are transported to developing or storage tissues, playing a vital role in stress tolerance and yield under adverse environmental conditions (Doan et al., 2024). In agriculture, leaf senescence significantly impacts yield and quality, especially in staple crops like wheat. The senescence process is regulated by intrinsic factors (e.g., aging) and external signals, including environmental stresses. Among them,



https://doi.org/10.59849/2710-4915.2024.2.06
Available online 31 December 2024

senescence plays a crucial role under drought and other abiotic stress conditions (Zhang et al., 2020).

Climate change remains one of the greatest challenges of the 21st century, profoundly impacting agriculture by altering growing conditions and posing severe threats to crop production. Increasing temperatures, unpredictable weather patterns, altered precipitation regimes, and more frequent extreme events such as droughts and floods are direct consequences of climate change, adversely affecting crops (Verma et al., 2024). These stress factors lead to reduced yields, decreased crop quality.

Proline plays a multifaceted role in plant senescence, acting as a critical adaptive molecule under both natural and stress-induced conditions. While proline is widely recognized for its contribution to stress tolerance, its role during senescence involves several interconnected physiological and molecular processes. Proline serves as both a stress mitigator and a regulator of senescence-associated processes. Its accumulation under stress conditions helps delay the detrimental effects of premature senescence, while its controlled metabolism facilitates nutrient redistribution and energy generation essential for programmed senescence. These complex roles position proline as a key molecule in elucidating the mechanisms underlying plant senescence, particularly under environmental stress conditions. Research on proline's regulatory networks and its interaction with other senescence-related factors is crucial for advancing our understanding of how plants adapt to stress and optimize their growth and productivity.

At the molecular level, leaf senescence involves significant changes in gene expression, regulated by senescence-associated genes (SAGs) (Cao et al., 2023). Transcription factors, including the WRKY family, play a pivotal role in these regulatory networks. WRKY proteins specifically bind to W-box elements in gene promoters, orchestrating various physiological responses, including nutrient redistribution and stress adaptation (Tan et al., 2024; Rushton et al., 2010). WRKY transcription factors are key regulators in plants, participating in diverse processes. They contain at least one WRKY domain, which is highly conserved across members, with approximately 60 amino acids in the N-terminal, and possess a characteristic zinc-finger structure in the C-terminal (Rushton et al., 2010). Based on the number of WRKY domains or zinc-finger structures, WRKYs are categorized into three groups. Group I contains two WRKY domains, including the CX4-5CX22-23HXH (C2H2) zinc-finger motif. Group IIa-e contains a single WRKY domain with a C2H2 motif, while Group III has a single WRKY domain and a CX7CX23HXC (C2HC) zinc-finger motif. The WRKY domain can specifically bind to the W-box ([T][T]TGAC[C/T]) in target gene promoters to regulate transcription (Rushton et al., 2010).

Recent studies reveal that several WRKY transcription factors play crucial roles in the regulatory networks of leaf senescence, exhibiting high expression levels in senescing leaves. Research on WRKY genes regulating senescence has primarily focused on model plants such as Arabidopsis and rice. However, there is limited information on senescence-related WRKYs in wheat. Recent findings have identified 116 WRKY members in the wheat genome, with 13 members upregulated during senescence in flag leaves (Borrill et al., 2019). Furthermore, 13 genes from the TaWRKY family have been confirmed as senescence-associated genes (SAGs).

The main objective of the study was to investigate the role of proline and WRKY transcription factors in regulating processes associated with drought-induced premature senescence in wheat plants.

## MATERIALS AND METHODS

***Cultivation of plant material.*** Seeds from local bread wheat (*Triticum aestivum* L.) genotypes, including the drought-tolerant Gyrmyzy gul 1 and the sensitive Tale 38**,** as well as durum wheat (*Triticum durum* Desf.) genotypes, the tolerant Vugar and the sensitive Tartar, were sourced from the gene pool of Research Institute of Crop Husbandry (Baku, Azerbaijan). The plants were grown in controlled environment chambers under control and drought conditions using a completely randomized design. During the entire experimental period, ambient

temperatures were controlled within the 19-29°C range, and relative humidity was maintained between 50% and 65%. Plants were cultivated under controlled conditions with a photoperiod of 16 hours of light and 8 hours of darkness. Flag leaves were collected at 7, 14, 21, 28, and 35 days post-anthesis. The collected leaf samples were immediately frozen in liquid nitrogen and stored at -80°C for further analysis.

***Determination of proline concentrations.*** Extraction and measurement of free proline were performed according to the acid ninhydrin method described by Bates et al (1973).

***RNA extraction and cDNA synthesis.*** Total RNA was isolated from leaf tissues using the Monarch Total RNA Miniprep Kit (New England Biolabs, Inc.) as per the manufacturer's guidelines. Genomic DNA was eliminated by treating the RNA with RNase-free DNase I. The integrity and purity of the extracted RNA were evaluated via agarose gel electrophoresis. RNA concentrations were determined using a NanoDrop Thermo Scientific-2000C spectrophotometer (USA). Complementary DNA (cDNA) synthesis was carried out from the isolated RNA using the LunaScript RT SuperMix Kit (New England Biolabs, Inc.), following the instructions provided by the manufacturer, in a final reaction volume of 20 µl.

***Quantitative real-time PCR.*** PCR was performed using a Mic Real-Time PCR system with a total reaction volume of 20 µl. Each reaction mixture consisted of 10 µl of Luna Universal qPCR Mix (New England Biolabs, Inc.), 1 µl of 1:5 diluted cDNA, 0.5 µl each of forward and reverse primers (10 µM), and 7 µl of nuclease-free water. The amplification protocol began with an initial denaturation at 94°C for 60 seconds, followed by 45 cycles at 95°C for 15 seconds and 60°C for 30 seconds. No-template controls (NTCs) were included for every primer pair. Each reaction was carried out in triplicate (technical replicates) for three biological replicates. Elongation factor 1 alpha (Elf1-α) served as the reference gene. The primer sequences utilized for expression analysis are provided in Table 1. Primer efficiency for each set was evaluated using the standard curve method with serial dilutions of cDNA, calculated using the equation: Efficiency (%) = (10^(-1/slope) - 1) × 100. Dissociation curves for each amplicon were examined to ensure the specificity of amplification. Relative gene expression levels (stressed versus control conditions) were determined using the 2^−ΔΔCt approach (Livak and Schmittgen, 2001).

**Table 1.** Sequences of primers used for qRT-PCR.

| Gene | Direction | Sequences |
|---|---|---|
| WRKY14 | F | GATGACATAGATGCTGGAGGTGG |
| | R | TGTGGCGTCGCTGTGGTT |
| WRKY36 | F | GTCAGCAGCCAGCCTTCCCTTAGCC |
| | R | CGTCGCCACGAGTATGGTCTTGTCC |
| Elf1-α | F | CAGATTGGCAACGGCTACG |
| | R | CGGACAGCAAAACGACCAAG |

**Statistical analysis:** The statistical analysis was carried out using SAS software ver9.2 (SAS Institute, 2008). Standard deviation (SD) values are from at least three biological replicates.

## RESULTS AND DISCUSSION

Proline content was measured in flag leaves at five-time points (7, 14, 21, 28, and 35 days after anthesis, DAA) during natural (age-induced) and drought-induced senescence in wheat genotypes with contrasting stress tolerance. In all genotypes, proline accumulation increased under drought conditions, peaking at 21 DAA, except for the highly drought-tolerant durum wheat genotype Vugar, which exhibited the highest increase in proline levels at 28 DAA (~6 µmol/mg fresh weight) (Fig. 1). This stage is likely critical for proline biosynthesis and coincides with increased sensitivity of plants to drought during the grain-filling period. Under control conditions, proline levels remained relatively stable and low at all developmental stages in all genotypes, with no distinct peaks. Despite a decline in proline levels at later stages, it remained higher than control values until the end of ontogenesis in drought-tolerant genotypes. In contrast, drought-sensitive genotypes (Tartar and Tale 38) also showed a peak in proline accumulation at 21 DAA (~5 and ~4 µmol/mg fresh weight, respectively); however, the decline in proline levels after the peak was more pronounced, indicating a less robust response to drought stress.

Plants have developed numerous defense mechanisms to mitigate the detrimental effects of

adverse environmental conditions. Among these mechanisms, the synthesis of protective compounds, including specific amino acids (e.g., proline), peptides (e.g., glutathione and phytochelatins), and polyamines (e.g., putrescine), plays a critical role (Hayat et al., 2012; Alcázar et al., 2020). The accumulation of proline under stress conditions has been confirmed in numerous plant species and is associated with adaptation to drought, salinity, or osmotic stress simulated by polyethylene glycol (PEG) (Hayat et al., 2012). Beyond its role as a widely distributed osmolyte, proline contributes to stress adaptation by scavenging reactive oxygen species (ROS), stabilizing proteins and intracellular structures, regulating intracellular redox potential, and acting as a signal molecule or heavy metal chelator (Hayat et al., 2012; Zdunek-Zastocka et al., 2021).

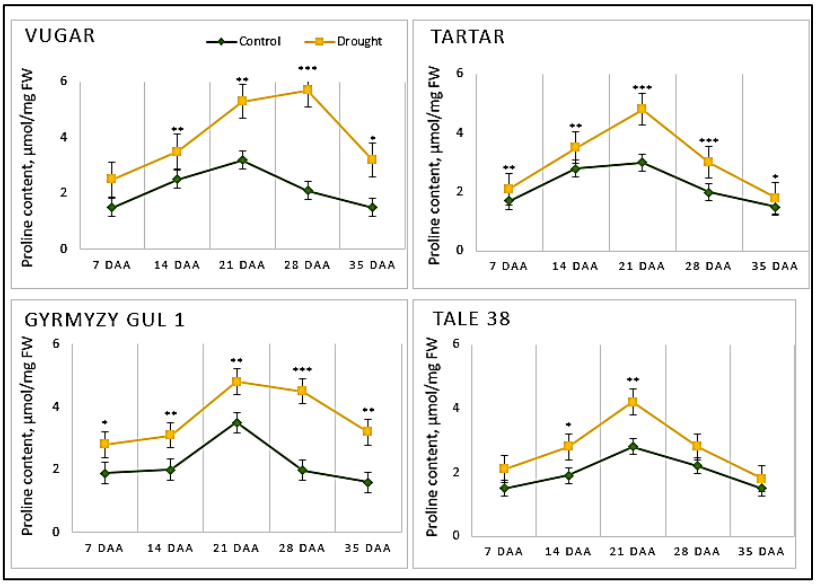


**Fig. 1.** Changes in proline content in wheat flag leaves during senescence. DAA – days after anthesis, FW – fresh weight. Data points represent the mean ± se (n = 5). Asterisks indicate the significance of differences (*P < 0.05, **P < 0.01, ***P < 0.001) using pairwise t-tests.

The expression of the *WRKY14* transcription factor gene exhibited varying dynamics depending on genotype and growth conditions (Fig. 2). In naturally senescing plants, the transcript levels of this gene sharply increased at the late stages of senescence. In drought-stressed plants, early senescence was observed in drought-tolerant genotypes, with the highly resilient durum wheat genotype Vugar showing an increase at 21 DAA, while in the tolerant bread wheat genotype Gyrmyzy gul 1, the rise occurred earlier, at 14 DAA. In drought-sensitive genotypes, a significant increase in *WRKY14* expression was observed at 35 DAA in the durum wheat genotype Tartar and at 28 DAA in the bread wheat genotype Tale 38. These findings indicate that the *WRKY14* transcription factor is more strongly induced by senescence than by the drought stress response itself and is more specific to the later stages of the senescence process.

The expression of the *WRKY36* transcription factor gene also varied depending on growth conditions, genotype, and plant developmental stage (Fig. 3). In plants grown under control conditions, the expression of this gene sharply increased at 35 DAA, during the most intensive phase of senescence. Under stress conditions, drought-tolerant genotypes exhibited earlier and higher *WRKY36* expression compared to sensitive genotypes. In the drought-tolerant durum wheat genotype, expression began increasing at 21 DAA, while in the drought-tolerant bread wheat genotype, the gene displayed significant transcription as early as 14 DAA. In contrast, sensitive genotypes showed a less pronounced increase in *WRKY36* expression, with a delayed peak at 35 DAA,

indicating less effective stress adaptation mechanisms. These findings underscore the critical role of *WRKY36* in enhancing plant resilience to abiotic stresses, particularly during the critical post-anthesis period.

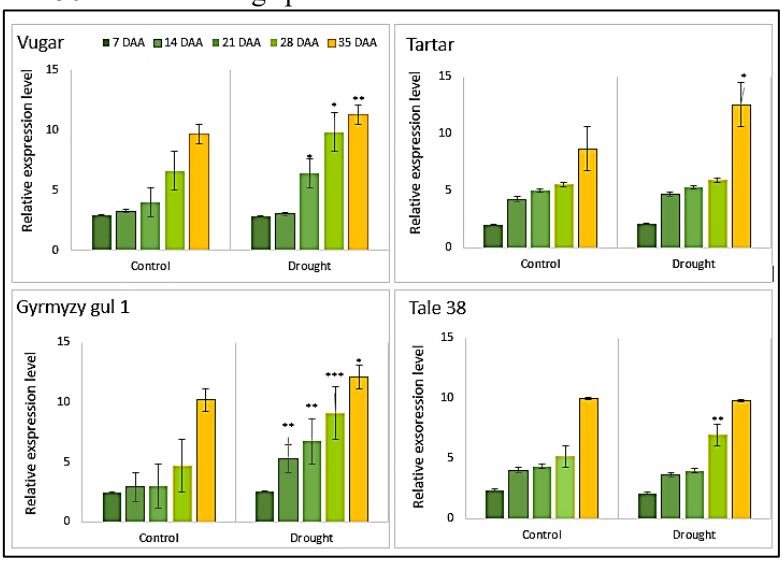


**Fig. 2.** Transcript level of WRKY14 transcription factor gene in flag leaves of wheat plants during natural and stress-induced senescence. DAA – days after anthesis. The fold change in expression was calculated using the $2^{-\Delta\Delta Ct}$ method. Bars represent the mean ± se (n=5). Asterisks indicate the significance of differences (*P < 0.05, **P < 0.01, ***P < 0.001) using pairwise t-tests.

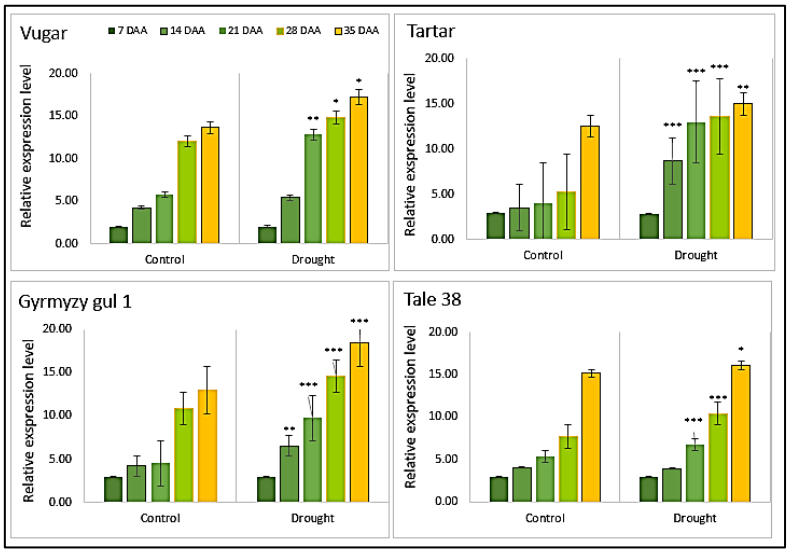


**Fig. 3.** Transcript level of WRKY36 transcription factor gene in flag leaves of wheat plants during natural and stress-induced senescence. DAA – days after anthesis. The fold change in expression was calculated using the $2^{-\Delta\Delta Ct}$ method. Bars represent the mean ± se (n = 5). Asterisks indicate the significance of differences (*P < 0.05, **P < 0.01, ***P < 0.001) using pairwise t-tests.

Its earlier activation in tolerant genotypes suggests that *WRKY36* contributes significantly to mitigating stress effects and delaying senescence under drought conditions.

Summarizing, it can be concluded that the *WRKY36* gene demonstrated higher expression

levels in drought-tolerant genotypes, especially under drought conditions, compared to *WRKY14.* This observation suggests a more active role for *WRKY36* in drought adaptation. The differences between the *WRKY14* and *WRKY36* genes are primarily attributed to their distinct signaling pathways and target genes. For instance, *WRKY14* targets include TaPR1 (pathogenesis-related protein), TaLOX2/3 (genes involved in jasmonate biosynthesis), and TaPAL (Baillo et al., 2019). In contrast, *WRKY36* regulates drought- and senescence-related genes such as *DREB2A* and *RD29A/B*. Despite these differences, both genes perform complementary functions, contributing to plant adaptation under stress conditions (Zhou et al., 2023). Increased expression of specific genes during senescence highlights the activation of pathways involved in the synthesis of proteins that either regulate or adapt to the aging process. For example, in rice, *AtWRKY6* directly regulates the transcription of senescence-induced receptor kinase (SIRK) genes via W-box promoter binding. Overexpression of *AtWRKY6* results in distinct phenotypes of premature and delayed senescence. Similarly, *AtWRKY53*, which regulates senescence-associated gene (SAG) expression, is induced by reactive oxygen species (ROS), emphasizing its role in oxidative stress signaling. Furthermore, *AtWRKY53* interacts with *AtWRKY30,* and its suppression by microRNAs prevents senescence phenotypes (Zeng et al., 2024). Other WRKY transcription factors such as *AtWRKY54, AtWRKY57*, and *AtWRKY70* also contribute significantly to regulating leaf senescence (Zhao et al., 2020). In wheat, *TaWRKY7* has been identified as a stress-responsive transcription factor, whose overexpression in Arabidopsis accelerates dark-induced leaf senescence. Its expression is upregulated under drought conditions and is associated with abscisic acid (ABA)-mediated stress responses. These findings highlight its dual role in senescence regulation and drought adaptation. Similarly, *TaWRKY42-B* has been identified as a positive regulator of leaf senescence in wheat. Its overexpression in Arabidopsis accelerates senescence, while its suppression in wheat delays both natural and dark-induced senescence. The interaction of *TaWRKY42-B* with jasmonate biosynthesis genes such as *TaLOX3* leads to jasmonate accumulation, triggering early senescence through JA-dependent signaling pathways.

Additionally, *TaWRKY14* has been shown to enhance chlorogenic acid biosynthesis in tobacco (*T. antungense*), illustrating its role in early stress adaptation. It also regulates the expression of pathogenesis-related genes and jasmonate biosynthesis genes, thereby enhancing plant defense against both biotic and abiotic stresses (Chen et al., 2023). Furthermore, its expression is upregulated under drought stress and linked to salicylic acid (SA)-dependent signaling pathways. These characteristics position *TaWRKY14* as a critical regulator of stress tolerance and senescence. Similarly, *TaWRKY36* has been associated with ABA-mediated signaling and the regulation of SAGs such as *SAG12* and *SAG29* during senescence. It also interacts with antioxidant defense genes, including catalase and superoxide dismutase, to mitigate ROS accumulation and maintain cellular stability under stress conditions (Vittozzi et al., 2024). These mechanisms highlight the functional importance of *WRKY36* in coordinating late-stage senescence and stress responses.

In conclusion, WRKY transcription factors play versatile roles in the regulation of senescence and stress responses. Their functional diversity and integration into hormonal and oxidative stress signaling pathways make them valuable targets for genetic improvement in crops. Further research on the precise mechanisms of WRKY-mediated regulation will provide critical insights for developing stress-resilient plant varieties.

## REFERENCES

**Alcázar R., Bueno M., Tiburcio A.T.** (2020) Polyamines: Small amines with large effects on plant abiotic stress tolerance. *Cells*, **9:** 2373.

**Baillo E.H., Kimotho R.N., Zhang Z., Xu P.** (2019) Transcription factors associated with abiotic and biotic stress tolerance and their potential for crops improvement. *Genes*, **10(10):** 771.

**Bates L.S., Waldren R.P., Teare I.D.** (1973) Rapid determination of free proline for water-stress studies. *Plant Soil*, **39:** 205-207.

**Borrill P., Harrington S. A., Simmonds J., & Uauy C.** (2019) Identification of transcription factors regulating senescence in wheat through gene regulatory network modelling. *Plant Physiol.*, *180(3)*: **1740–1755.**

**Cao J., Liu H., Tan S., Li Z.** (2023) Transcription factors-regulated leaf senescence: Current knowledge, challenges, and approaches. *International Journal of Molecular Sciences*, **24(11):** 9245.

**Chen L., Xiang S., Chen Y., Li Y.** (2023) *Regulation of WRKY transcription factors in plant immunity and stress responses*. *Plant Cell Reports*, **42:** 567–580.

**Doan P.P.T., Vuong H.H., & Kim J.** (2024) Genetic Foundation of Leaf Senescence: Insights from Natural and Cultivated Plant Diversity. *Plants*, ***13(23)*:** 3405.

**Gregersen P.L., Culetic A., Boschian L., & Krupinska K.** (2013) Plant senescence and crop productivity. *Plant Mol. Biol.*, ***82*:** 603–622.

**Guo Y., Ren G., Zhang K., Li Z., Miao Y., & Guo H.** (2021). Leaf senescence: progression, regulation, and application. *Mol. Hortic.*, ***1*: 1–25.**

**Hayat S. et al.** (2012) Role of proline under changing environments. *Plant Signal. Behav*., **7:** 1456-1466.

**Li P., Pan Q., et al.** (2024) Improving crop productivity by optimizing straw returning patterns to delay senescence of wheat leaves. *Eur. J. Agron.*, ***159*:** 127274.

**Lim P.O., Kim H.J., Nam H.G.** (2007) Leaf senescence. *Annual Review of Plant Biology*, **58: 115-136.**

**Livak K.J., & Schmittgen T.D.** (2001) Analysis of relative gene expression data using real-time quantitative PCR and the 2−ΔΔCT method. *Methods*, ***25(4)*:** 402–408.

**Rushton P.J., Somssich I.E., Ringler P., Shen Q.J.** (2010) WRKY transcription factors. *Trends in Plant Science*, **15(5):** 247-258.

**Saeed A., Ahmed H.G.M.D., Zeng Y., Fatima N., Hussain G. S., Akram M.I., ... & Mushtaq M. A.** (2024) Genetic evaluation and breeding strategies under water deficit environment to develop the drought-tolerant wheat germplasm. *Pol. J. Environ. Stud.*, **33(6)**: 1–12.

**Tan Q., Zhao M., Gao J.et al.** (2024) AtVQ25 promotes salicylic acid-related leaf senescence by fine-tuning the self-repression of AtWRKY53. *Journal of Integrative Plant Biology*, **66(1)**: 103–114.

**Verma K.K. et al.** (2024). Climate change adaptation: Challenges for agricultural sustainability. *Plant, Cell & Environment*, **47(8):** 15078

**Vittozzi Y., Krüger T., Majee A., Née G., & Wenkel S.** (2024). ABI5 binding proteins: key players in coordinating plant growth and development. *Trends Plant Sci.*, ***29(9)*:** 1006–1017.

**Zdunek-Zastocka E., Grabowska A., Michniewska B., Orzechowski S.** (2021) Proline concentration and its metabolism are regulated in a leaf age dependent manner but not by abscisic acid in pea plants exposed to cadmium stress. *Cells*, **10(4**): 946.

**Zeng Y., et al.** (2024). WRKY proteins regulate the development of plants in response to abiotic stresses. *J. Plant Interact.*, ***19(1)*:** 2299865.

**Zhang H. et al.** (2020) Abscisic acid promotes leaf senescence in wheat. *Frontiers in Plant Science*, **11:** 1234.

**Zhao M.M., Zhang X.W., Liu Y.W., Li K., Tan Q., Zhou S., ... & Zhou C.J.** (2020) A WRKY transcription factor, TaWRKY42-B, facilitates initiation of leaf senescence by promoting jasmonic acid biosynthesis. *BMC Plant Biol.*, ***20*:** 1–22.

**Zhou Y. et al.** (2023) Differential regulation of WRKY14 and WRKY36 in response to drought and senescence. *Plant Molecular Biology*, **111:** 89-102.

**ORCIDS:**

Turana Isgandarova: https://orcid.org/0000-0002-6287-9220
Samira Rustamova: https://orcid.org/0000-0001-5337-7109
Tofig Allahverdiyev: https://orcid.org/0000-0002-6039-7068
Irada Huseynova: https://orcid.org/0000-0003-3336-2203

*Journal of Life Sciences & Biomedicine, vol. 6(79), No 2, p. 13-32 (2024)*

# Does molecular docking between the cement protein of barnacles and resin acids open a new gate for the development of eco-friendly antifouling paint?

**Ibrahim Kirkiz, Levent Cavas***

*Department of Chemistry (Biochemistry Division), Faculty of Science, Dokuz Eylül University, Kaynaklar Campus, 35390, İzmir, Türkiye*

***For correspondence:** levent.cavas@deu.edu.tr*

Received: September 1, 2024; Received in revised form: October 17, 2024; Accepted: November 6, 2024

**As a result of the surfaces of ships being covered with fouling organisms, ships begin to consume more fuel to reach their destinations. Excessive fuel consumption by ships causes carbon emissions to increase. This increase in carbon emissions is one of the main reasons for climate change and biodiversity loss because it causes ocean acidification. Another factor affecting biodiversity is antifouling paints containing biocides. In antifouling paints, released compounds accumulate in sediments and marine organisms. These compounds interact differently with various organisms to achieve antifouling abilities. To understand the molecular interactions between cement proteins from *Amphibalanus amphitrite* and resin acids, molecular docking was carried out comprehensively in the present study. For molecular docking, CB-Docking was used to estimate the bonding energies. According to the results, the best interaction was found between dehydroabietic acid and *A. amphitrite* CP-20k-2 and the binding energy was -8.0 kcal/mol. The weakest binding energy was observed between neoabietic acid and *A. amphitrite* CP-20k-1 with -4.7 kcal/mol. In conclusion, the molecular docking between specific proteins responsible for fouling activity and the chemical that will be used in the formulation of new eco-friendly antifouling paints can correctly estimate the antifouling performance. Moreover, the *in-silico* methods can decrease the cost and time for R&D studies of new-generation eco-friendly antifouling paints.**

***Keywords:*** *Biofouling, antifouling, barnacles, cement protein, molecular docking*

## INTRODUCTION

Marine biofouling is the attachment of living organisms to surfaces that are immersed in marine environments (Gule et al., 2016). Both organic and inorganic materials can attach to the surfaces, making total accumulation on the surface easier. Fouling organisms, such as barnacles, tubeworms, and mussels, adhere to surfaces and populate. This phenomenon can occur on any surface immersed in seawater. In general terms, biofouling occurs in several steps. The first step is the enrichment of the surface with organic materials, which is called the conditioning film layer. This process takes minutes to form. The formation and contents of the conditioning film layer are crucial for the attachment of marine organisms. Subsequently, microorganisms start populating the film layer, and as time passes, more organisms attach to the surface, including macrofouling organisms such as barnacles and mussels (Yebra et al., 2004; Sarkar et al., 2022).

Biofouling has some negative effects on marine-related industries. Biofouling can cause clogging in pipes, filter systems, and aquaculture nets. However, the main reason that marine biofouling draws much attention is its effects on marine vessels. In particular, the hulls and propellers of ships are negatively affected by biofouling. Normally, hulls are smooth surfaces, but with biofouling, the surface becomes rough, thus increasing surface friction. Increased surface friction will decrease the speed, and this will cause the consumption of more fuel to

https://doi.org/10.59849/2710-4915.2024.2.13
Available online 31 December 2024

compensate for the speed loss. Biofouling can also cause the transportation of invasive species to different ecosystems. This issue negatively affects the biodiversity of ecosystems because most invasive species are aggressive toward other organisms (Carve et al., 2019; Farkas et al., 2021).

There are different types of fouling organisms, but barnacles are the most studied species. The reason for this is their adhesion mechanisms. Barnacles use an adhesive called cement to attach surfaces underwater (Kamino, 2013; Liang et al., 2019; Dreyer et al., 2020). Because of this feature, scientists are studying barnacle cement to create commercial adhesives that perform in the same way underwater.

Barnacles are sessile crustaceans. Because they do not have any limbs to move themselves, they move around by the movements of the water column (Kamino et al., 2012; Ip et al., 2021). Barnacles go through four phases in their lives. Nauplius is the larval stage of a barnacle (Nasrolahi et al., 2016; Ewers-Saucedo and Pappalardo, 2019). Nauplius transforms into cyprids when they grow to a sufficient size (Kamino, 2016; Liu et al., 2016). Cyprids move around with the movements of the water column to seek a surface to settle. Their primary function is to find a surface to settle (Aldred and Clare, 2008). When cyprids find a suitable surface, they secrete a temporary adhesive called a footprint (Yap et al., 2017). With this adhesive, cyprids attach to surfaces reversibly. After this stage, the cyprid transforms into a juvenile barnacle. Then, the juvenile becomes an adult barnacle and secretes cement to irreversibly attach. Cement is secreted from the cement gland (Kamino, 2016; Yan et al., 2020).

Cement contains approximately 85% protein, but not all of them have been identified (Walker, 1972; Kamino et al., 1996). Different cement proteins are used in underwater adhesion, and they all have different functions. On the other hand, there are some proteins that have been identified according to their functions. CP-100k and CP-52k are hydrophobic proteins with high molecular weights. They are the main components of cement that hold other molecules together (Kamino, 2016; Rocha et al., 2019; Wong et al., 2023). CP-68k contains charged amino acids. Therefore, it might be responsible for interactions with foreign surfaces (Yuvaraj et al., 2021). There are also small polypeptides such as CP-20k. CP-20k does not bond with other cement proteins, and because of this feature, it is likely a coupling agent that interacts with another barnacle cement (Jonker et al., 2014; Li et al., 2021). CP-19k contains amino acid compounds similar to CP-68k. CP-19k is absorbed by different materials such as glass and polystyrene. Therefore, CP-19k may be responsible for the adhesion process (Rocha et al., 2019). Another small protein is CP-16k, which has similarities with litotic enzymes. With this feature, CP-16k protects the cement structure from marine micro and macro organisms (Li et al., 2021).

With the regulations brought to the antifouling technology, more and more compounds are being tested for their natural antifouling abilities (Almeida and Vasconcelos, 2015). Methods used to determine the performance of antifouling paints require time, labor, and money. When the chosen natural compound does not perform as desired in seawater, the above resources are wasted. For this reason, *in silico* tools can be used to at least have an idea about the interactions between natural compounds and target molecules (Assadizadeh et al., 2023; Cavas and Dağ, 2024).

The search for natural bioactive materials is increasing rapidly. Resin is one of those materials because trees release it to deal with infections due to pathogens. In particular, resin acids have great potential because of their antimicrobial activities (Savluchinske-Feio et al., 2006; Dimkić et al., 2016). Resin acids have functional groups such as aldehydes, hydroxyls, and ketones to increase their antimicrobial performance. Resin acids mostly consist of terpenoids. Rosin, a rich source of diterpenes, is obtained from pine resin after steam distillation (Ottavioli et al., 2019). Diterpene resin acids are 20-carbon and cyclic carboxylic acids. Rosin contains tricyclic diterpene acids such as abietic, dehydroabietic, isopimaric, levopimaric, neoabietic, palustric, pimaric, and sandaracopimaric acids (Martin et al., 1999; Keeling and Bohlmann, 2006). The tricyclic structures of diterpenes are given in Figure 1.

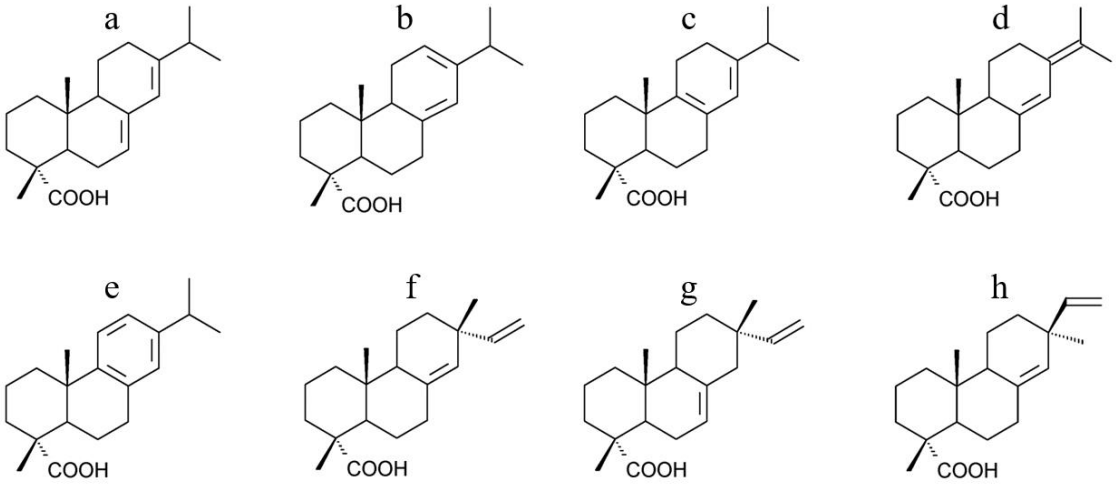


**Fig. 1.** Chemical structures of resin acids (a) abietic acid, (b) levopimaric acid, (c) palustric acid, (d) neoabietic acid, (e) dehydroabietic acid, (f) sandaracopimaric acid, (g) isopimaric acid, (h) pimaric acid.

## MATERIALS AND METHODS

The sequences for the cement protein 20k (CP-20k) *Amphibalanus amphitrite* were retrieved from UniProt (The UniProt Consortium, 2023). Sequences of three CP-20k fragments were obtained for *A. amphitrite* (CP-20k-1, CP-20k-2, CP-20k-3). Accession numbers are K7X3K6, K7XZK5, and K7X9M0, respectively. The 3D structures of *A. amphitrite* fragments were modeled using SWISS-MODEL (Waterhouse et al., 2018). The 3D structures of resin acids (abietic acid, levopimaric acid, palustric acid, neoabietic acid, dehydroabietic acid, sandaracopimaric acid, isopimaric acid and pimaric acid) were retrieved from PubChem (Kim et al., 2023). Molecular docking studies were performed using CB-Dock2 (Liu et al., 2022).

## RESULTS

***Protein modeling:*** Because the 3D structures of the three *A. amphitrite* CP-20k fragments were absent in Uniport, 3D structures were obtained using SWISS-MODEL (Waterhouse et al., 2018). When modeling these proteins, templates with the highest coverage and lowest resolution were chosen. As can be seen from Figure 2, each protein fragment has different structures because of its amino acids and molecular interactions.

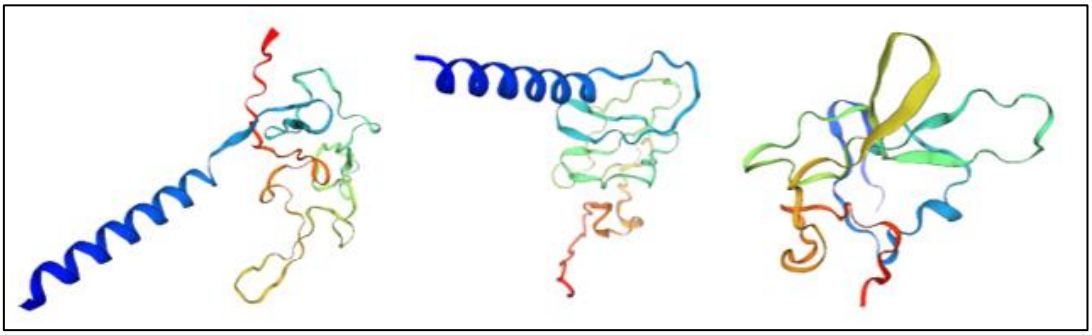

**Fig. 2.** Modeled 3D structure of *A. amphitrite* CP-20k-1, CP-20k-2, and CP-20k-3 fragments using SWISS-MODEL.

https://doi.org/10.59849/2710-4915.2024.2.13
Available online 31 December 2024

***Molecular docking:*** After modeling all three cement proteins, molecular docking analysis was conducted using CB-Dock2 (Liu et al., 2022). Resin acids were used as ligands. In this section, the molecular docking results of abietic, dehydroabietic, and levopimaric acids, which have the highest binding affinities.

CB-Dock2 predicts the protein-ligand binding sites and calculates the binding effectiveness using a cavity-based detection system. CB-Dock2 predicts five cavities with the lowest binding energies. In Figure 3, instead of giving the results of all binding sites, only cavities with the lowest binding energies are given. Figure 3 shows the molecular interactions between protein fragments and ligands.

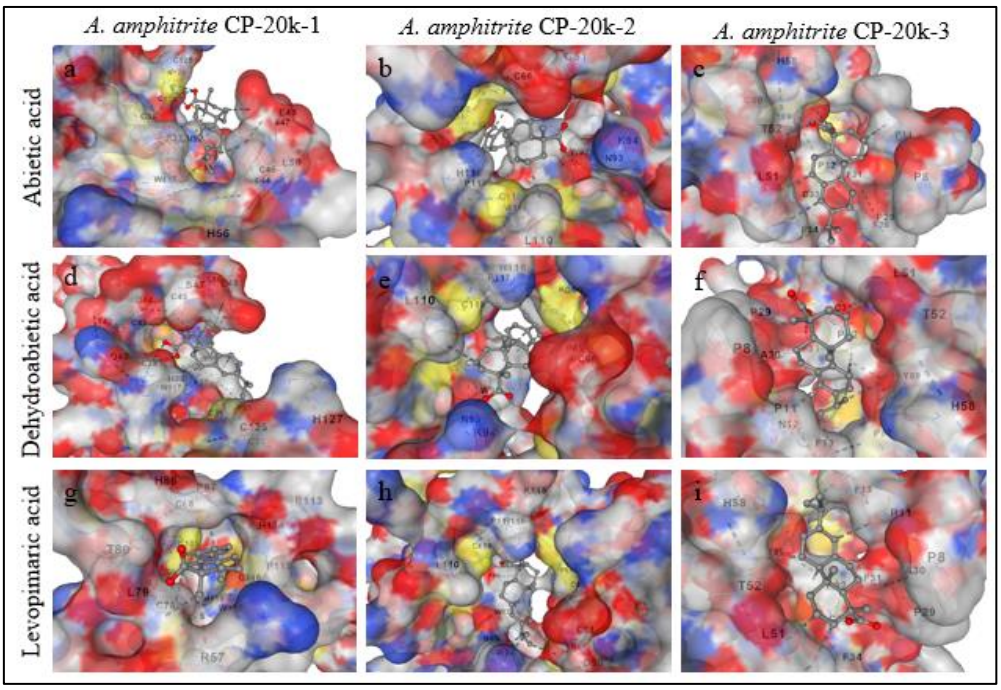


**Fig. 3.** Molecular docking images of cavities with the highest binding affinities between a) *A. amphitrite* CP-20k-1 and abietic acid, b) *A. amphitrite* CP-20k-2 and abietic acid, c) *A. amphitrite* CP-20k-3 and abietic acid, d) *A. amphitrite* CP-20k-1 and dehydroabietic acid, e) *A. amphitrite* CP-20k-2 and dehydroabietic acid, f) *A. amphitrite* CP-20k-3 and dehydroabietic acid, g) *A. amphitrite* CP-20k-1 and levopimaric acid, h) *A. amphitrite* CP-20k-2 and levopimaric acid, i) *A. amphitrite* CP-20k-3 and levopimaric acid.

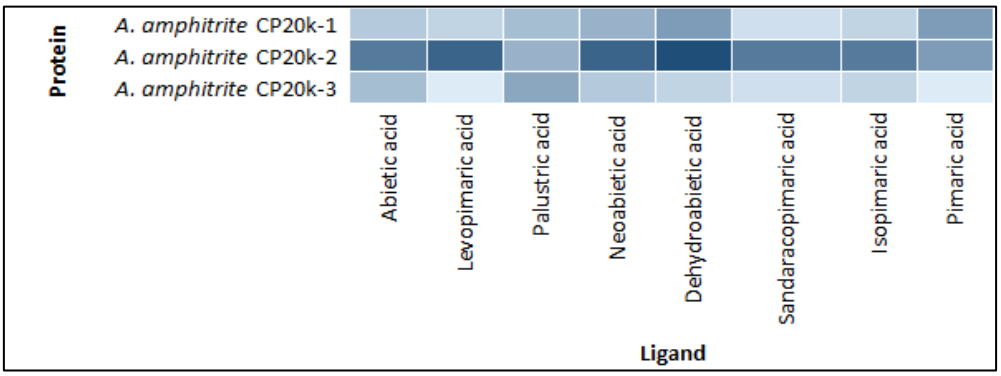


**Fig. 4.** Molecular docking heatmap of CP20k protein fragments and resin acids (binding affinities are displayed by color. The darker color means lower binding energy, which indicates better binding).

**Table 1.** Molecular docking results of abietic acid with *Amphibalanus amphitrite* CP-20k-1

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-1 | C1 | -6.4 | 600 | 2, -1, 1 | 21, 21, 21 | **Chain A**: PRO35 PHE37 CYS39 GLN40 ASP41 THR42 CYS43 ARG57 GLU73 CYS74 ASN75 CYS76 ASN77 LEU79 THR80 SER85 HIS86 PRO87 CYS88 CYS105 ASP106 ILE112 ARG113 HIS114 PRO115 CYS116 TRP117 HIS118 ARG119 |
| | C2 | -6.4 | 357 | -8, 0, 11 | 21, 21, 21 | **Chain A**: ALA23 ARG24 GLY25 GLN26 LYS27 ARG28 ASN29 CYS30 ASN31 ASN34 CYS36 ASP106 SER107 ILE108 GLU109 CYS110 SER111 ILE112 ARG113 CYS116 HIS118 GLU120 CYS121 GLY122 CYS123 |
| | C3 | -6.9 | 325 | 2, 9, 0 | 21, 21, 21 | **Chain A**: CYS30 CYS36 PHE37 HIS38 CYS39 CYS43 ASP44 CYS45 SER47 GLU48 LEU50 HIS56 TRP117 CYS121 GLY122 CYS123 ASN124 CYS125 HIS127 |
| | C4 | -5.9 | 113 | -5, 10, 15 | 21, 21, 21 | **Chain A**: CYS30 ASN31 PRO32 ASN34 PRO35 CYS36 PHE37 HIS38 SER47 GLU48 LEU50 CYS123 ASN124 CYS125 THR126 HIS127 THR128 ALA129 |
| | C5 | -5.1 | 36 | 4, -8, -7 | 21, 21, 21 | **Chain A:** ARG57 HIS60 CYS76 ASN77 HIS78 LEU79 THR80 PRO81 CYS82 ASP83 HIS86 PRO87 CYS88 TRP89 TYR101 ASP102 CYS103 ASP104 CYS105 ASP106 PRO115 TRP117 |

**Table 2**. Molecular docking results of abietic acid with *Amphibalanus amphitrite* CP-20k-2

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-2 | C1 | -7.6 | 6765 | 4, 1, -7 | 32, 27, 35 | **Chain A**: CYS38 GLY39 CYS44 TYR45 TYR46 CYS47 ASP50 CYS51 GLU52 CYS53 HIS54 LEU56 HIS57 ASP58 GLN59 CYS60 LYS61 PRO62 HIS64 PRO65 CYS66 TYR67 ARG68 LEU70 ASP78 CYS79 HIS81 VAL82 LYS83 PRO84 TRP92 ASN93 LYS94 TYR95 THR96 VAL97 GLN103 ASN106 HIS109 LEU110 HIS116 PRO117 CYS118 TRP119 |
| | C2 | -6.1 | 391 | -5, -8, -15 | 21, 21, 21 | **Chain A**: CYS85 ASN86 HIS89 CYS91 GLN103 ARG104 CYS105 ASN106 CYS107 ASP108 HIS109 TRP119 HIS120 ARG121 HIS122 CYS123 ASP124 CYS125 |
| | C3 | -6.8 | 89 | -8, -11, -7 | 21, 21, 21 | **Chain A**: GLN59 CYS60 LYS61 PRO62 HIS89 CYS112 ASN113 ARG114 LYS115 HIS116 PRO117 CYS118 TRP119 HIS120 CYS123 ASP124 CYS125 TYR126 CYS127 LYS128 |
| | C4 | -7.2 | 72 | -1, 4, 10 | 21, 21, 21 | **Chain A**: CYS38 GLY39 PRO40 HIS42 ARG43 CYS44 TYR45 TYR46 CYS47 CYS53 HIS54 LEU56 HIS57 ASP58 GLN59 CYS60 LYS61 SER63 HIS64 PRO65 CYS66 TYR67 PHE75 CYS77 CYS79 |
| | C5 | -6.6 | 42 | 3, 6, 16 | 21, 21, 21 | **Chain A**: HIS33 LYS34 SER35 ARG36 HIS37 CYS38 GLY39 CYS44 TYR45 TYR46 CYS47 GLU52 CYS53 HIS54 HIS55 LEU56 HIS57 ASP58 GLN59 CYS60 HIS64 CYS66 |

**Table 3.** Molecular docking results of abietic acid with *Amphibalanus amphitrite* CP-20k-3

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-3 | C1 | -7.0 | 3269 | 1, -3, 1 | 21, 27, 30 | **Chain A**: ASN7 PRO8 PRO11 ASN12 PHE13 ASN14 CYS15 THR16 SER18 CYS19 CYS21 LEU24 PRO28 PRO29 ALA30 PHE31 PRO32 CYS33 PHE34 LEU51 THR52 PRO53 HIS58 CYS60 TRP61 ASP72 ASN73 ASN74 CYS75 ASP76 CYS77 ASP78 ILE80 ALA81 CYS82 SER83 THR84 PRO87 CYS88 TYR89 HIS90 ARG91 GLN92 CYS93 SER94 CYS95 ASP96 |
| | C2 | -5.7 | 110 | 16, -1, -2 | 21, 21, 21 | **Chain A**: CYS19 ASP20 CYS21 ALA22 GLU23 LEU24 ARG25 ASN40 GLU41 THR42 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 HIS90 ARG91 GLN92 |
| | C3 | -5.5 | 107 | 19, 4, 4 | 21, 21, 21 | **Chain A**: CYS19 ASP20 CYS21 ALA22 GLU23 LEU24 ARG25 CYS27 PRO28 PRO29 CYS33 PHE34 ARG35 LEU36 PRO37 SER38 GLU41 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 GLN50 LEU51 TRP61 THR63 LEU70 HIS90 ARG91 |
| | C4 | -5.7 | 89 | 0, 4, -13 | 21, 21, 21 | **Chain A**: CYS1 LYS2 GLY3 PRO4 PRO5 CYS6 ASN10 PRO11 ASN12 PHE13 ASN14 CYS15 THR16 SER18 CYS19 ASP20 CYS21 GLU23 LEU24 PRO28 PRO29 ALA30 PHE31 PRO32 THR84 SER85 HIS86 PRO87 CYS88 |
| | C5 | -6.0 | 63 | 16, 6, -4 | 21, 21, 21 | **Chain A**: PRO4 PRO5 CYS6 ASN7 PRO8 ASN12 GLU23 LEU24 ARG25 TYR26 CYS27 PRO28 PRO29 ALA30 PHE31 PRO32 CYS33 PHE34 ARG35 LEU36 PRO37 SER38 GLU41 THR42 GLU43 PRO44 LEU51 |

**Table 4.** Molecular docking results of dehydroabietic acid with *Amphibalanus amphitrite* CP-20k-1

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-1 | C1 | -6.7 | 600 | 2, -1, 1 | 20, 20, 20 | **Chain A**: PRO35 PHE37 CYS39 GLN40 ASP41 THR42 CYS43 ARG57 CYS58 CYS74 ASN75 CYS76 ASN77 LEU79 THR80 SER85 HIS86 PRO87 CYS88 CYS105 ASP106 ARG113 HIS114 PRO115 CYS116 TRP117 HIS118 ARG119 |
| | C2 | -6.0 | 357 | -8, 0, 11 | 20, 20, 20 | **Chain A**: ALA23 ARG24 GLY25 GLN26 LYS27 ARG28 ASN29 ASN31 ASN34 CYS36 ASP106 SER107 ILE108 GLU109 CYS110 SER111 ILE112 ARG113 CYS116 GLU120 CYS121 GLY122 CYS123 |
| | C3 | -7.3 | 325 | 2, 9, 0 | 20, 20, 20 | **Chain A**: CYS30 PRO35 CYS36 PHE37 HIS38 CYS39 GLN40 THR42 CYS43 ASP44 CYS45 SER46 SER47 GLU48 GLY49 LEU50 PHE51 CYS52 HIS56 VAL72 GLU73 CYS74 TRP117 CYS121 GLY122 CYS123 ASN124 CYS125 HIS127 |
| | C4 | -5.7 | 113 | -5, 10, 15 | 20, 20, 20 | **Chain A**: GLN26 LYS27 ARG28 ASN29 CYS30 ASN31 PRO32 ASN34 PRO35 CYS36 PHE37 HIS38 SER47 GLU48 LEU50 CYS123 ASN124 CYS125 THR126 HIS127 THR128 ALA129 |
| | C5 | -4.9 | 36 | 4, -8, -7 | 20, 20, 20 | **Chain A:** HIS60 GLU73 ASN75 CYS76 ASN77 HIS78 LEU79 THR80 PRO81 CYS82 ASP83 TRP89 TYR101 ASP102 CYS103 ASP104 ASP106 ARG119 |

**Table 5.** Molecular docking results of dehydroabietic acid with *Amphibalanus amphitrite* CP-20k-2

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-2 | C1 | -8.0 | 6765 | 4, 1, -7 | 32, 27, 35 | **Chain A**: CYS38 CYS44 TYR45 TYR46 CYS47 HIS48 ASP50 CYS51 GLU52 CYS53 HIS54 HIS57 ASP58 CYS60 LYS61 PRO62 HIS64 PRO65 CYS66 TYR67 ARG68 LEU70 ASP78 CYS79 HIS81 VAL82 LYS83 PRO84 CYS85 PRO87 LYS88 HIS89 PRO90 CYS91 TRP92 ASN93 LYS94 TYR95 THR96 VAL97 LYS98 HIS101 LYS102 GLN103 ARG104 CYS105 ASN106 HIS109 LEU110 HIS116 PRO117 CYS118 TRP119 |
| | C2 | -6.2 | 391 | -5, -8, -15 | 20, 20, 20 | **Chain A**: CYS85 ASN86 PRO87 HIS89 CYS91 LYS102 GLN103 ARG104 CYS105 ASN106 CYS107 ASP108 HIS109 LEU110 ARG111 CYS112 TRP119 HIS120 ARG121 HIS122 CYS123 ASP124 CYS125 |
| | C3 | -6.3 | 89 | -8, -11, -7 | 20, 20, 20 | **Chain A**: CYS60 LYS61 PRO62 LYS88 HIS89 ASP108 LEU110 ARG111 CYS112 ASN113 ARG114 HIS116 PRO117 CYS118 TRP119 HIS120 HIS122 CYS123 ASP124 CYS125 TYR126 CYS127 |
| | C4 | -7.3 | 72 | -1, 4, 10 | 20, 20, 20 | **Chain A**: CYS38 GLY39 PRO40 HIS42 ARG43 CYS44 TYR45 TYR46 CYS53 HIS54 HIS55 LEU56 HIS57 ASP58 GLN59 CYS60 LYS61 SER63 HIS64 PRO65 CYS66 TYR67 |
| | C5 | -6.5 | 42 | 3, 6, 16 | 20, 20, 20 | **Chain A**: HIS33 LYS34 SER35 ARG36 HIS37 CYS38 CYS44 TYR45 TYR46 CYS47 CYS53 HIS54 HIS55 LEU56 HIS57 ASP58 GLN59 HIS64 |

**Table 6.** Molecular docking results of dehydroabietic acid with *Amphibalanus amphitrite* CP-20k-3

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-3 | C1 | -6.8 | 3269 | 1, -3, 1 | 26, 27, 30 | **Chain A**: ASN7 PRO8 GLY9 ASN10 PRO11 ASN12 PHE13 CYS19 ASP20 CYS21 ALA22 CYS27 PRO28 PRO29 ALA30 PHE31 PRO32 CYS33 PHE34 ARG35 CYS46 ASP47 CYS48 ASN49 LEU51 THR52 SER57 HIS58 THR84 SER85 HIS86 PRO87 CYS88 TYR89 HIS90 ARG91 GLN92 |
| | C2 | -5.8 | 110 | 16, -1, -2 | 20, 20, 20 | **Chain A**: CYS19 ASP20 CYS21 ALA22 GLU23 LEU24 ARG25 TYR26 CYS33 ARG35 ASN40 GLU41 THR42 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 HIS90 ARG91 GLN92 |
| | C3 | -5.3 | 107 | 19, 4, 4 | 20, 20, 20 | **Chain A**: ASP20 CYS21 ALA22 LEU24 PHE34 ARG35 LEU36 PRO37 SER38 GLY39 ASN40 GLU41 THR42 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 GLN50 TRP61 THR63 VAL65 LEU70 ARG91 |
| | C4 | -5.8 | 89 | 0, 4, -13 | 20, 20, 20 | **Chain A**: CYS1 LYS2 GLY3 PRO4 PRO5 CYS6 ASN10 PRO11 ASN12 PHE13 ASN14 THR16 SER18 ASP20 GLU23 LEU24 PRO28 ALA30 PHE31 THR84 SER85 PRO87 |
| | C5 | -5.7 | 63 | 16, 6, -4 | 20, 20, 20 | **Chain A**: PRO5 CYS6 ASN12 GLU23 LEU24 ARG25 TYR26 CYS27 PRO28 PRO29 ALA30 PHE31 CYS33 PHE34 ARG35 LEU36 PRO37 SER38 LEU51 |

**Table 7.** Molecular docking results of levopimaric acid with *Amphibalanus amphitrite* CP-20k-1

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-1 | C1 | -6.8 | 600 | 2, -1, 1 | 20, 20, 20 | **Chain A**: ARG57 CYS58 CYS76 LEU79 THR80 SER85 HIS86 PRO87 CYS88 CYS105 ILE112 ARG113 HIS114 PRO115 CYS116 TRP117 HIS118 |
| | C2 | -6.7 | 357 | -8, 0, 11 | 20, 20, 20 | **Chain A**: ALA23 ARG24 GLY25 GLN26 LYS27 ARG28 ASP106 ILE108 GLU109 CYS110 CYS116 HIS118 GLU120 CYS121 CYS123 |
| | C3 | -6.3 | 325 | 2, 9, 0 | 20, 20, 20 | **Chain A**: CYS36 PHE37 HIS38 CYS39 THR42 CYS43 ASP44 CYS45 SER46 SER47 GLU48 LEU50 PHE51 CYS52 HIS56 VAL72 GLU73 CYS74 TRP117 GLY122 CYS123 ASN124 CYS125 THR126 HIS127 |
| | C4 | -5.8 | 113 | -5, 10, 15 | 20, 20, 20 | **Chain A**: ASN29 CYS30 ASN31 PRO32 ASN34 PRO35 CYS36 PHE37 HIS38 GLU48 LEU50 CYS125 THR126 HIS127 THR128 ALA129 |
| | C5 | -4.9 | 36 | 4, -8, -7 | 20, 20, 20 | **Chain A:** HIS60 ASN75 ASN77 HIS78 LEU79 THR80 PRO81 CYS82 ASP83 TYR101 ASP102 CYS103 ASP104 ASP106 |

**Table 8.** Molecular docking results of levopimaric acid with *Amphibalanus amphitrite* CP-20k-2

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-2 | C1 | -7.8 | 6765 | 4, 1, -7 | 32, 27, 35 | **Chain A**: ASP50 CYS51 GLU52 CYS60 LYS61 PRO62 HIS64 PRO65 CYS66 TYR67 ARG68 LEU70 PRO71 HIS81 VAL82 LYS83 PRO84 PRO90 TRP92 ASN93 LYS94 TYR95 THR96 VAL97 LYS98 HIS101 LYS102 GLN103 ARG104 CYS105 ASN106 LEU110 LYS115 HIS116 PRO117 CYS118 |
| | C2 | -6.1 | 391 | -5, -8, -15 | 20, 20, 20 | **Chain A**: CYS85 ASN86 HIS89 CYS91 LYS102 GLN103 ARG104 CYS105 ASN106 CYS107 ASP108 HIS109 TRP119 HIS120 ARG121 HIS122 CYS123 ASP124 |
| | C3 | -6.0 | 89 | -8, -11, -7 | 20, 20, 20 | **Chain A**: GLN59 CYS60 LYS61 PRO62 HIS89 CYS112 ASN113 ARG114 HIS116 PRO117 CYS118 TRP119 HIS120 ARG121 HIS122 CYS123 ASP124 CYS125 TYR126 CYS127 |
| | C4 | -7.1 | 72 | -1, 4, 10 | 20, 20, 20 | **Chain A**: CYS38 GLY39 ARG43 CYS44 TYR45 TYR46 CYS47 CYS53 HIS54 HIS55 LEU56 HIS57 ASP58 GLN59 CYS60 LYS61 SER63 HIS64 PRO65 CYS66 TYR67 PHE75 CYS77 CYS79 |
| | C5 | -6.2 | 42 | 3, 6, 16 | 20, 20, 20 | **Chain A**: HIS33 LYS34 SER35 ARG36 CYS38 GLY39 CYS44 TYR45 TYR46 CYS47 GLU52 CYS53 HIS54 HIS55 LEU56 HIS57 ASP58 GLN59 HIS64 |

**Table 9.** Molecular docking results of levopimaric acid with *Amphibalanus amphitrite* CP-20k-3

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-3 | C1 | -6.6 | 3269 | 1, -3, 1 | 26, 27, 30 | **Chain A**: ASN7 PRO8 GLY9 PRO11 PHE13 ASN14 THR16 SER18 CYS19 ASP20 CYS21 ALA22 GLU23 LEU24 CYS27 PRO28 PRO29 ALA30 PHE31 PRO32 CYS33 PHE34 ARG35 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 LEU51 THR52 HIS58 TRP61 THR63 LEU70 ASP72 ASN73 ASN74 CYS75 ASP76 CYS77 ASP78 TYR89 HIS90 ARG91 GLN92 |
| | C2 | -5.6 | 110 | 16, -1, -2 | 20, 20, 20 | **Chain A**: CYS19 ASP20 CYS21 ALA22 GLU23 LEU24 GLU41 THR42 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 HIS90 ARG91 GLN92 |
| | C3 | -5.5 | 107 | 19, 4, 4 | 20, 20, 20 | **Chain A**: ASP20 CYS21 ALA22 LEU24 ARG25 CYS33 LEU36 PRO37 SER38 GLY39 ASN40 GLU41 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 TRP61 THR63 LEU70 ARG91 |
| | C4 | -5.7 | 89 | 0, 4, -13 | 20, 20, 20 | **Chain A**: CYS1 LYS2 GLY3 PRO4 PRO5 CYS6 ASN10 PRO11 ASN12 PHE13 ASN14 CYS15 THR16 SER18 CYS19 ASP20 CYS21 GLU23 LEU24 PRO28 PRO29 ALA30 PHE31 THR84 SER85 PRO87 |
| | C5 | -5.6 | 63 | 16, 6, -4 | 20, 20, 20 | **Chain A**: PRO4 PRO5 CYS6 GLU23 LEU24 ARG25 TYR26 CYS27 PRO28 PRO29 ALA30 PHE31 CYS33 PHE34 ARG35 PRO37 LEU51 |

Sometimes cavities with the lowest vina score are not the effective areas for a protein to function. For this reason, the properties of all cavities obtained by CB-Dock2 are presented in Table 1-9. For every interaction, vina scores (kcal/mol), cavity volumes (Å$^3$) and contact residues are given. Same as before, only the results of abietic, dehydroabietic and levopimaric acids are given. The molecular docking results of the remaining resin acids are given in the Supplementary File (Table S1-S15).

To better visualize the molecular docking results, a heatmap was plotted using Microsoft Excel. As can be seen from Figure 4, the lowest binding energy belongs to dehydroabietic acid and *A. amphitrite* CP20k-2. Moreover, almost all resin acids bind *A. amphitrite* CP20k-2 better than the other two proteins. Generally, binding energies less than -5 kcal/mol indicate better binding affinity (Shuyuan and Haoyu, 2023).

## DISCUSSION

Barnacles are a major problem in underwater studies. In the past biocide-containing toxic paints were used to deal with biofouling. After their usage was banned, more and more eco-friendly paints were introduced. However, they are not as effective as toxic paints, and they lose their effectiveness after some time. When paints reach their half-life, hard fouler like barnacles start to accumulate on the surface. Therefore, an investigation must be conducted on how to deal with hard fouling organisms, especially barnacles, in an eco-friendly manner. To do that the attachment mechanisms of barnacles must be enlightened because it is still not clear how they achieve underwater attachment. So far, we know that barnacles use cement to attach to surfaces and this cement contains high amounts of proteins (Walker, 1972; Kamino et al., 1996; Naldrett and Kaplan, 1997; Kamino et al., 2000; Khandeparker and Anil, 2007; Lin et al., 2021). Each protein has different functions in the attachment mechanism. Among them, CP19k and CP20k are thought to be responsible for the attachment (Assadizadeh et al., 2023). Therefore, more studies should be conducted on these proteins. In this paper, the molecular docking of resin acids to the CP20k fragments was studied and promising results were obtained. By looking at our results, one can say that barnacle CP20k fragments and resin acids surely interact with acceptable binding energies. *In silico* studies such as this one may lead to the

development of new compounds with antifouling abilities. New antifouling compounds can be tested using computational analysis methods instead of field tests. In this way, it will be less time and resource-consuming to test the antifouling ability of a compound.

## CONCLUSION

*A. amphitrite* CP20k is a cement protein that barnacles use to attach rigidly to the surfaces. Therefore, studying this cement protein is crucial for understanding its attachment mechanisms. Rosin is a natural compound with antifouling ability. When its composition was studied, it was found that rosin has a high amount of resin acids. These resin acids can be effective molecules in antifouling technologies. Therefore, the interactions between cement protein and resin acids were investigated in this study. Molecular docking results of abietic, dehydroabietic and levopimaric acids are given in the paper. Molecular docking results of the other resin acids are given in the Supplementary File. When all interactions were examined, between the three protein fragments, CP20k-2 had the lowest vina scores, and the best interaction was between *A. amphitrite* CP20k-2 and dehydroabietic acid. These findings are promising in biocide-free antifouling strategies since antifouling properties can be tested before field tests. Biocide-free antifouling coatings will solve the biofouling problem in an eco-friendly way. Thus, it will reduce carbon emissions of ships and biodiversity loss

## SUPPORTING MATERIAL

Additional molecular docking results were given.

## AUTHOR CONTRIBUTIONS

**Ibrahim Kirkiz:** Data curation, Investigation, Methodology, Writing - original draft, Writing - review & editing. **Levent Cavas:** Conceptualization, Investigation, Supervision. Writing - review & editing.

## COMPETING INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## FUNDING SOURCES

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## REFERENCES

**Aldred N., Clare A.S.** (2008) The adhesive strategies of cyprids and development of barnacle-resistant marine coatings. *Biofouling*, **24(5):** 351-363; doi: 10.1080/08927010802256117.

**Almeida J.R., Vasconcelos V.** (2015) Natural antifouling compounds: Effectiveness in preventing invertebrate settlement and adhesion. *Biotechnology Advances*, **33(3-4):** 343-357; doi: 10.1016/j.biotechadv.2015.01.013.

**Assadizadeh M., Goodarz N., Pak A.H.M., Haghayeghi S.M.H., Irani M.A.** (2023) Structural investigation of *Amphibalanus amphitrite* cement proteins: an in silico study. *Bioinspired, Biomimetic and Nanobiomaterials*, **12(4):** 140-152; doi: 10.1680/jbibn.23.00008.

**Carve M., Scardino A., Shimeta J.** (2019) Effects of surface texture and interrelated properties on marine biofouling: a systematic review. *Biofouling*, **35(6):** 597-617; doi: 10.1080/08927014.2019.1636036.

**Cavas L., Dağ C.** (2024) In-silico methods in antifouling paint technology. *World Intellectual Property Organization. International Publication Number* WO2024144682A1. https://patents.google.com/patent/WO2024144682A1/en.

**Dimkić I., Ristivojević P., Janakiev T., Berić T., Trifković J., Milojković-Opsenica D., Stanković S.** (2016) Phenolic profiles and antimicrobial activity of various plant resins as potential botanical sources of Serbian

propolis. *Industrial Crops and Products*, **94:** 856-871; doi: 10.1016/j.indcrop.2016.09.065.

**Dreyer N., Zardus J.D., Høeg J.T., Olesen J., Yu M.C., Chan B.K.** (2020) How whale and dolphin barnacles attach to their hosts and the paradox of remarkably versatile attachment structures in cypris larvae. *Organisms Diversity & Evolution*, **20:** 233-249; doi: 10.1007/s13127-020-00434-3.

**Ewers-Saucedo C., Pappalardo P.** (2019) Testing adaptive hypotheses on the evolution of larval life history in acorn and stalked barnacles. *Ecology and Evolution*, **9(19):** 11434-11447; https://doi.org/10.1002/ece3.5645.

**Farkas A., Degiuli N., Martić I.** (2021) The impact of biofouling on the propeller performance. *Ocean Engineering*, **219:** 108376. https://doi.org/10.1016/j.oceaneng.2020.108376.

**Gule N.P., Begum, N.M., Klumperman B.** (2016) Advances in biofouling mitigation: A review. *Critical Reviews in Environmental Science and Technology*, **46(6):** 535-555; https://doi.org/10.1080/10643389.2015.1114444

**Ip J.C.H., Qiu J.W., Chan B.K.** (2021) Genomic insights into the sessile life and biofouling of barnacles (*Crustacea: Cirripedia*). *Heliyon*, **7(6):** e07291; doi: 10.1016/j.heliyon.2021.e07291.

**Jonker J.L., Abram F., Pires E., Varela Coelho A., Grunwald I., Power A.M.** (2014) Adhesive proteins of stalked and acorn barnacles display homology with low sequence similarities. *PLoS One*, **9(10):** e108902; doi: 10.1371/journal.pone.0108902.

**Kamino K.** (2013) Mini-review: barnacle adhesives and adhesion. *Biofouling*, **29(6):** 735-749; doi: 10.1080/08927014.2013.800863.

**Kamino K.** (2016) Barnacle Underwater Attachment. *In: Smith, A. (eds) Biological Adhesives*. Springer: Cham; doi: 10.1007/978-3-319-46082-6_7.

**Kamino K., Inoue K., Maruyama T., Takamatsu N., Harayama S., Shizuri Y.** (2000) Barnacle cement proteins: importance of disulfide bonds in their insolubility. *Journal of Biological Chemistry*, **275(35):** 27360-27365. https://doi.org/10.1016/S0021-9258(19)61519-X.

**Kamino K., Nakano M., Kanai S.** (2012) Significance of the conformation of building blocks in curing of barnacle underwater adhesive. *The FEBS Journal*, **279(10):** 1750-1760; doi: 10.1111/j.1742-4658.2012.08552.x.

**Kamino K., Odo S., Maruyama,T.** (1996) Cement proteins of the acorn-barnacle, Megabalanus rosa. *The Biological Bulletin*, **190(3):** 403-409; doi:10.2307/1543033.

**Keeling C.I., Bohlmann J.** (2006). Diterpene resin acids in conifers. *Phytochemistry*, **67(22):** 2415-2423; doi: 10.1016/j.phytochem.2006.08.019.

**Khandeparker L., Anil A.C.** (2007) Underwater adhesion: the barnacle way. *International Journal of Adhesion and Adhesives*, **27(2):** 165-172; doi: 10.1016/j.ijadhadh.2006.03.004.

**Kim S., Chen J., Cheng T., Gindulyte A., He J., He S., Li Q., Shoemaker B.A., Thiessen P.A., Yu B., Zaslavsky L., Zhang J., Bolton E.E.** (2023). PubChem 2023 update. *Nucleic Acids Research*, **51(D1):** D1373-D1380; doi: 10.1093/nar/gkac956.

**Li X., Li S., Huang X., Chen Y., Cheng J., Zhan A.** (2021) Protein-mediated bioadhesion in marine organisms: A review. *Marine Environmental Research*, **170:** 105409; doi: 10.1016/j.marenvres.2021.105409.

**Liang C., Strickland J., Ye Z., Wu W., Hu B., Rittschof D.** (2019) Biochemistry of barnacle adhesion: an updated review. *Frontiers in Marine Science*, **6:** 565; doi: 10.3389/fmars.2019.00565.

**Lin H.C., Wong Y.H., Sung C.H., Chan B.K.K.** (2021) Histology and transcriptomic analyses of barnacles with different base materials and habitats shed lights on the duplication and chemical diversification of barnacle cement proteins. *BMC Genomics*, **22:** 1-18; https://doi.org/10.1186/s12864-021-08049-4.

**Liu J.C.W., Høeg J.T., Chan B.K.** (2016) How do coral barnacles start their life in their hosts? *Biology Letters*, **12(6):** 20160124. https://doi.org/10.1098/rsbl.2016.0124.

**Liu Y., Yang X., Gan J., Chen S., Xiao Z.X., Cao Y.** (2022) CB-Dock2: Improved protein–ligand blind docking by integrating cavity detection, docking and homologous template fitting. *Nucleic Acids Research*, **50(W1):** W159-W164; https://doi.org/10.1093/nar/gkac394.

**Martin V.J., Yu Z., Mohn W.W.** (1999) Recent

advances in understanding resin acid biodegradation: microbial diversity and metabolism. *Archives of Microbiology*, **172:** 131-138; https://doi.org/10.1007/s002030050752.

**Naldrett M.J., Kaplan D.L.** (1997) Characterization of barnacle (Balanus eburneus and B. cenatus) adhesive proteins. *Marine Biology*, **127:** 629-635; doi: 10.1007/s002270050053.

**Nasrolahi A., Havenhand J., Wrange A.L., Pansch C.** (2016) Population and life-stage specific sensitivities to temperature and salinity stress in barnacles. *Scientific Reports*, **6(1):** 32263; https://doi.org/10.1038/srep32263.

**Ottavioli J., Paoli M., Casanova J., Tomi F., Bighelli A.** (2019) Identification and quantitative determination of resin acids from *Corsican pinus pinaster* Aiton oleoresin using $^{13}$C-NMR Spectroscopy. *Chemistry & Biodiversity*, **16(1):** e1800482; doi: 10.1002/cbdv.201800482.

**Rocha M., Antas P., Castro L.F.C., Campos A., Vasconcelos V., Pereira F., Cunha I.** (2019) Comparative analysis of the adhesive proteins of the adult stalked goose barnacle *Pollicipes pollicipes* (*Cirripedia: Pedunculata*). *Marine Biotechnology*, **21:** 38-51; doi: 10.1007/s10126-018-9856-y.

**Sarkar P.K., Pawar S.S., Rath S.K., Kandasubramanian B.** (2022) Anti-barnacle biofouling coatings for the protection of marine vessels: synthesis and progress. *Environmental Science and Pollution Research*, **29(18):** 26078-26112; doi: 10.1007/s11356-021-18404-3.

**Savluchinske-Feio S., Curto M.J.M., Gigante B., Roseiro J.C.** (2006) Antimicrobial activity of resin acid derivatives. *Applied Microbiology and Biotechnology*, **72:** 430-436; doi: 10.1007/s00253-006-0517-0.

**Shuyuan L., Haoyu C.** (2023) Mechanism of Nardostachyos Radix et Rhizoma–Salidroside in the treatment of premature ventricular beats based on network pharmacology and molecular docking. *Scientific Reports*, **13(1):** 20741; https://doi.org/10.1038/s41598-023-48277-0.

**The UniProt Consortium** (2023) UniProt: the Universal Protein Knowledgebase in 2023, *Nucleic Acids Research*, **51(D1):** D523-D531; https://doi.org/10.1093/nar/gkac1052.

**Walker G.** (1972) The biochemical composition of the cement of two barnacle species, Balanus hameri and Balanus crenatus. *Journal of the Marine Biological Association of the United Kingdom*, **52(2):** 429-435; doi: 10.1017/S0025315400018786.

**Waterhouse A., Bertoni M., Bienert S., Studer G., Tauriello G., Gumienny R., Heer F., de Beer T.A.P., Rempfer C., Bordoli L., Lepore R., Schwede T.** (2018) SWISS-MODEL: homology modelling of protein structures and complexes. *Nucleic Acids Research*, **46(W1):** W296-W303; doi: 10.1093/nar/gky427.

**Wong Y.H., Dreyer N., Liu H., Lan Y., Chen J.J., Sun J., ... Chan B.K.** (2023) Gene co-option, duplication and divergence of cement proteins underpin the evolution of bioadhesives across barnacle life histories. *Molecular Ecology*, **32(18):** 5071-5088; doi: 10.1111/mec.17084.

**Yan G., Sun J., Wang Z., Qian P.Y., He L.** (2020) Insights into the synthesis, secretion and curing of barnacle cyprid adhesive via transcriptomic and proteomic analyses of the cement gland. *Marine Drugs*, **18(4):** 186; doi: 10.3390/md18040186.

**Yap F.C., Wong W.L., Maule A.G., Brennan G.P., Chong V.C., Lim L.H.S.** (2017) First evidence for temporary and permanent adhesive systems in the stalked barnacle cyprid, *Octolasmis angulata*. *Scientific Reports*, **7(1):** 44980; doi: 10.1038/srep44980.

**Yebra D.M., Kiil S., Dam-Johansen K.** (2004) Antifouling technology - past, present and future steps towards efficient and environmentally friendly antifouling coatings. *Progress in Organic Coatings*, **50(2):** 75-104; https://doi.org/10.1016/j.porgcoat.2003.06.001.

**Yuvaraj D., Annushrie A., Niranjana M., Gnanasekaran R., Gopinath M., Iyyappan J.** (2021) A review on process and characterization of mussels and cirripeds for adhesive properties and applications thereof. *Current Research in Green and Sustainable Chemistry*, **4:** 100092. https://doi.org/10.1016/j.crgsc.2021.100.

# Supplementary Materials

**Table S1.** Molecular docking results of neoabietic acid with *Amphibalanus amphitrite* CP-20k-1

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-1 | C1 | -7.1 | 600 | 2, -1, 1 | 21, 21, 21 | **Chain A**: PRO35 PHE37 CYS39 GLN40 ASP41 THR42 CYS43 ARG57 CYS58 GLU73 CYS74 ASN75 CYS76 ASN77 LEU79 THR80 SER85 HIS86 PRO87 CYS88 ASP104 CYS105 ASP106 ILE112 ARG113 HIS114 PRO115 CYS116 TRP117 HIS118 ARG119 |
| | C2 | -6.2 | 357 | -8, 0, 11 | 21, 21, 21 | **Chain A**: ALA23 ARG24 GLY25 GLN26 LYS27 ARG28 CYS36 CYS105 ASP106 SER107 ILE108 GLU109 CYS110 CYS116 HIS118 GLU120 CYS121 GLY122 CYS123 ASN124 |
| | C3 | -6.7 | 325 | 2, 9, 0 | 21, 21, 21 | **Chain A**: CYS30 CYS36 PHE37 HIS38 CYS39 CYS43 ASP44 CYS45 SER46 SER47 GLU48 LEU50 HIS56 TRP117 GLY122 CYS123 ASN124 CYS125 HIS127 |
| | C4 | -6.1 | 113 | -5, 10, 15 | 21, 21, 21 | **Chain A**: CYS30 ASN31 PRO32 ASN34 PRO35 CYS36 PHE37 HIS38 SER47 GLU48 LEU50 CYS123 ASN124 CYS125 THR126 HIS127 THR128 ALA129 |
| | C5 | -4.7 | 36 | 4, -8, -7 | 21, 21, 21 | **Chain A:** HIS60 ILE61 VAL63 ASN65 ASN77 HIS78 LEU79 THR80 PRO81 CYS82 THR100 TYR101 ASP102 CYS103 ASP104 CYS105 ASP106 |

**Table S2.** Molecular docking results of neoabietic acid with *Amphibalanus amphitrite* CP-20k-2

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-2 | C1 | -7.8 | 6765 | 4, 1, -7 | 32, 27, 35 | **Chain A**: ASP50 CYS51 GLU52 CYS53 CYS60 LYS61 PRO62 HIS64 PRO65 CYS66 TYR67 ARG68 CYS79 ASN80 VAL82 PRO84 PRO90 TRP92 ASN93 LYS94 TYR95 THR96 VAL97 LYS98 HIS101 LYS102 GLN103 ARG104 CYS105 ASN106 LEU110 LYS115 HIS116 PRO117 CYS118 TRP119 |
| | C2 | -6.7 | 391 | -5, -8, -15 | 21, 21, 21 | **Chain A**: CYS85 ASN86 HIS89 CYS91 LYS102 GLN103 ARG104 CYS105 ASN106 CYS107 ASP108 HIS109 LEU110 ARG111 CYS112 TRP119 HIS120 ARG121 HIS122 CYS123 CYS125 |
| | C3 | -6.5 | 89 | -8, -11, -7 | 21, 21, 21 | **Chain A**: GLN59 CYS60 LYS61 PRO62 HIS89 CYS107 ASP108 HIS109 LEU110 ARG111 CYS112 ASN113 ARG114 HIS116 PRO117 CYS118 TRP119 HIS120 HIS122 CYS123 ASP124 CYS125 TYR126 CYS127 LYS128 |
| | C4 | -7.4 | 72 | -1, 4, 10 | 21, 21, 21 | **Chain A**: HIS33 ARG36 CYS38 GLY39 PRO40 HIS42 ARG43 CYS44 TYR45 TYR46 CYS47 GLU52 CYS53 HIS54 HIS55 LEU56 HIS57 ASP58 GLN59 CYS60 LYS61 HIS64 PRO65 CYS66 TYR67 |
| | C5 | -6.8 | 42 | 3, 6, 16 | 21, 21, 21 | **Chain A**: HIS33 LYS34 SER35 ARG36 HIS37 CYS38 CYS44 TYR45 TYR46 CYS47 HIS48 GLU52 CYS53 HIS54 HIS55 LEU56 HIS57 ASP58 GLN59 HIS64 CYS66 TYR67 |

**Table S3.** Molecular docking results of neoabietic acid with *Amphibalanus amphitrite* CP-20k-3

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-3 | C1 | -6.9 | 3269 | 1, -3, 1 | 21, 27, 30 | **Chain A**: ASN7 PRO8 GLY9 PRO11 ASN12 PHE13 ASN14 CYS15 THR16 SER18 CYS19 CYS21 PRO28 PRO29 ALA30 PHE31 PRO32 CYS33 PHE34 LEU51 THR52 SER57 HIS58 ASP78 ILE80 ALA81 CYS82 SER83 PRO87 CYS88 TYR89 HIS90 GLN92 CYS93 SER94 CYS95 ASP96 |
| | C2 | -5.4 | 110 | 16, -1, -2 | 21, 21, 21 | **Chain A**: CYS19 ASP20 CYS21 ALA22 GLU23 LEU24 ARG25 GLU41 THR42 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 TYR89 HIS90 ARG91 GLN92 |
| | C3 | -5.8 | 107 | 19, 4, 4 | 21, 21, 21 | **Chain A**: ASP20 CYS21 ALA22 LEU24 CYS33 LEU36 PRO37 SER38 GLY39 ASN40 GLU41 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 GLN50 TRP61 THR63 VAL65 LEU70 HIS90 ARG91 |
| | C4 | -6.0 | 89 | 0, 4, -13 | 21, 21, 21 | **Chain A**: CYS1 GLY3 PRO4 PRO5 CYS6 ASN7 ASN10 PRO11 ASN12 PHE13 ASN14 CYS15 THR16 SER18 CYS19 ASP20 CYS21 GLU23 LEU24 PRO28 ALA30 PHE31 PRO32 THR84 SER85 PRO87 CYS88 TYR89 |
| | C5 | -5.7 | 63 | 16, 6, -4 | 21, 21, 21 | **Chain A**: PRO4 PRO5 CYS6 ASN7 ASN12 GLU23 LEU24 ARG25 TYR26 CYS27 PRO28 PRO29 ALA30 PHE31 CYS33 PHE34 ARG35 LEU36 PRO37 LEU51 |

**Table S4.** Molecular docking results of palustiric acid with *Amphibalanus amphitrite* CP-20k-1

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-1 | C1 | -6.4 | 600 | 2, -1, 1 | 21, 21, 21 | **Chain A**: PRO35 PHE37 CYS39 GLN40 ASP41 THR42 CYS43 ARG57 GLU73 CYS74 ASN75 CYS76 ASN77 LEU79 THR80 SER85 HIS86 PRO87 CYS88 CYS105 ASP106 ILE112 ARG113 HIS114 PRO115 CYS116 TRP117 HIS118 ARG119 |
| | C2 | -7.0 | 357 | -8, 0, 11 | 21, 21, 21 | **Chain A**: ALA23 ARG24 GLY25 GLN26 LYS27 ARG28 ASP106 SER107 ILE108 GLU109 CYS110 SER111 CYS116 GLU120 CYS121 GLY122 CYS123 |
| | C3 | -6.8 | 325 | 2, 9, 0 | 21, 21, 21 | **Chain A**: CYS30 PRO35 CYS36 PHE37 HIS38 CYS39 GLN40 CYS43 ASP44 CYS45 SER47 GLU48 LEU50 HIS56 TRP117 CYS121 GLY122 CYS123 ASN124 CYS125 THR126 HIS127 |
| | C4 | -5.8 | 113 | -5, 10, 15 | 21, 21, 21 | **Chain A**: ASN29 CYS30 ASN31 PRO32 ASN34 PRO35 CYS36 PHE37 HIS38 CYS39 SER47 GLU48 LEU50 GLY122 CYS123 ASN124 CYS125 THR126 HIS127 THR128 |
| | C5 | -5.1 | 36 | 4, -8, -7 | 21, 21, 21 | **Chain A:** HIS60 GLU73 ASN75 CYS76 ASN77 HIS78 LEU79 THR80 PRO81 CYS82 TRP89 TYR101 ASP102 CYS103 ASP104 CYS105 ASP106 ARG119 |

**Table S5.** Molecular docking results of palustiric acid with *Amphibalanus amphitrite* CP-20k-2

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-2 | C1 | -7.9 | 6765 | 4, 1, -7 | 32, 27, 35 | **Chain A**: CYS38 CYS44 TYR45 TYR46 ASP50 CYS51 GLU52 CYS53 HIS54 HIS55 LEU56 HIS57 ASP58 GLN59 CYS60 LYS61 PRO62 HIS64 PRO65 CYS66 TYR67 ARG68 LEU70 ASP78 HIS81 VAL82 LYS83 PRO84 CYS85 CYS91 TRP92 ASN93 LYS94 TYR95 THR96 VAL97 LYS98 HIS101 LYS102 GLN103 ARG104 CYS105 ASN106 HIS109 LEU110 HIS116 PRO117 CYS118 TRP119 |
| | C2 | -6.3 | 391 | -5, -8, -15 | 21, 21, 21 | **Chain A**: CYS85 ASN86 HIS89 CYS91 GLN103 ARG104 CYS105 ASN106 CYS107 ASP108 HIS109 LEU110 ARG111 CYS112 PRO117 CYS118 TRP119 HIS120 ARG121 HIS122 CYS123 ASP124 CYS125 |
| | C3 | -7.0 | 89 | -8, -11, -7 | 21, 21, 21 | **Chain A**: GLN59 CYS60 LYS61 PRO62 HIS89 ASP108 LEU110 ARG111 CYS112 ASN113 ARG114 LYS115 HIS116 PRO117 CYS118 TRP119 HIS120 HIS122 CYS123 ASP124 CYS125 TYR126 CYS127 LYS128 |
| | C4 | -7.1 | 72 | -1, 4, 10 | 21, 21, 21 | **Chain A**: CYS38 GLY39 PRO40 HIS42 ARG43 CYS44 TYR45 TYR46 CYS47 CYS53 HIS54 LEU56 HIS57 ASP58 GLN59 CYS60 LYS61 SER63 HIS64 PRO65 CYS66 TYR67 |
| | C5 | -6.6 | 42 | 3, 6, 16 | 21, 21, 21 | **Chain A**: HIS33 LYS34 SER35 ARG36 CYS38 ARG43 CYS44 TYR45 TYR46 CYS47 HIS48 GLU52 CYS53 HIS54 HIS55 LEU56 HIS57 ASP58 GLN59 HIS64 CYS66 |

**Table S6.** Molecular docking results of palustiric acid with *Amphibalanus amphitrite* CP-20k-3

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-3 | C1 | -7.2 | 3269 | 1, -3, 1 | 21, 27, 30 | **Chain A**: PRO4 CYS6 ASN7 PRO8 GLY9 ASN10 PRO11 ASN12 PHE13 ASN14 CYS15 THR16 SER18 CYS19 ASP20 CYS21 GLU23 LEU24 TYR26 PRO28 PRO29 ALA30 PHE31 PRO32 CYS33 PHE34 LEU51 THR52 SER57 HIS58 CYS60 TRP61 ASP72 ASN73 ASN74 CYS75 ASP76 CYS77 ASP78 ILE80 ALA81 CYS82 SER83 PRO87 CYS88 TYR89 HIS90 ARG91 GLN92 CYS93 SER94 CYS95 ASP96 |
| | C2 | -6.0 | 110 | 16, -1, -2 | 21, 21, 21 | **Chain A**: CYS19 ASP20 CYS21 ALA22 GLU23 LEU24 ARG25 TYR26 PRO28 ASN40 GLU41 THR42 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 HIS90 ARG91 GLN92 |
| | C3 | -5.5 | 107 | 19, 4, 4 | 21, 21, 21 | **Chain A**: CYS19 ASP20 CYS21 ALA22 LEU24 ARG25 PHE34 LEU36 PRO37 SER38 GLY39 ASN40 GLU41 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 GLN50 TRP61 THR63 VAL65 LEU70 HIS90 ARG91 |
| | C4 | -6.2 | 89 | 0, 4, -13 | 21, 21, 21 | **Chain A**: CYS1 LYS2 GLY3 PRO4 PRO5 CYS6 GLY9 ASN10 PRO11 ASN12 PHE13 ASN14 THR16 SER18 CYS19 ASP20 CYS21 GLU23 LEU24 PRO28 ALA30 PHE31 THR84 SER85 CYS88 |
| | C5 | -6.0 | 63 | 16, 6, -4 | 21, 21, 21 | **Chain A**: PRO4 PRO5 CYS6 ASN7 ASN12 GLU23 LEU24 ARG25 TYR26 CYS27 PRO28 PRO29 ALA30 PHE31 PRO32 CYS33 PHE34 ARG35 LEU36 PRO37 SER38 LEU51 |

**Table S7.** Molecular docking results of sandaracopimaric acid with *Amphibalanus amphitrite* CP-20k-1

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-1 | C1 | -6.6 | 600 | 2, -1, 1 | 20, 20, 20 | **Chain A**: ARG57 CYS76 LEU79 THR80 SER85 HIS86 PRO87 CYS88 CYS105 ILE112 ARG113 HIS114 PRO115 CYS116 TRP117 HIS118 |
| | C2 | -6.2 | 357 | -8, 0, 11 | 20, 20, 20 | **Chain A**: ALA23 ARG24 GLY25 GLN26 LYS27 ARG28 ASN29 ASN31 ASN34 CYS36 ASP106 SER107 ILE108 GLU109 CYS110 SER111 ILE112 ARG113 CYS116 HIS118 GLU120 CYS121 GLY122 CYS123 |
| | C3 | -6.7 | 325 | 2, 9, 0 | 20, 20, 20 | **Chain A**: CYS36 PHE37 HIS38 CYS39 THR42 CYS43 ASP44 CYS45 SER46 SER47 GLU48 GLY49 LEU50 PHE51 CYS52 HIS56 TRP117 CYS123 CYS125 HIS127 |
| | C4 | -5.6 | 113 | -5, 10, 15 | 20, 20, 20 | **Chain A**: GLN26 LYS27 ARG28 ASN29 CYS30 ASN31 PRO32 ASN34 PRO35 CYS36 PHE37 HIS38 SER47 GLU48 LEU50 CYS123 CYS125 THR126 HIS127 THR128 ALA129 |
| | C5 | -4.8 | 36 | 4, -8, -7 | 20, 20, 20 | **Chain A:** HIS60 ILE61 HIS62 VAL63 ASN77 HIS78 LEU79 THR80 PRO81 CYS82 ASP83 HIS86 TRP89 TYR101 ASP102 CYS103 ASP104 ASP106 |

**Table S8.** Molecular docking results of sandaracopimaric acid with *Amphibalanus amphitrite* CP-20k-2

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-2 | C1 | -7.6 | 6765 | 4, 1, -7 | 32, 27, 35 | **Chain A**: CYS38 CYS44 TYR45 TYR46 CYS47 ASP50 CYS51 GLU52 CYS53 HIS54 LEU56 HIS57 ASP58 GLN59 CYS60 LYS61 HIS64 PRO65 CYS66 TYR67 ARG68 LEU70 HIS81 VAL82 LYS83 PRO84 CYS85 CYS91 TRP92 ASN93 LYS94 TYR95 THR96 VAL97 GLN103 LEU110 LYS115 HIS116 PRO117 CYS118 |
| | C2 | -6.1 | 391 | -5, -8, -15 | 20, 20, 20 | **Chain A**: CYS85 ASN86 HIS89 CYS91 LYS102 GLN103 ARG104 CYS105 ASN106 CYS107 ASP108 HIS109 LEU110 ARG111 CYS112 TRP119 HIS120 ARG121 HIS122 CYS123 ASP124 CYS125 |
| | C3 | -6.3 | 89 | -8, -11, -7 | 20, 20, 20 | **Chain A**: GLN59 CYS60 LYS61 PRO62 HIS89 CYS112 ASN113 ARG114 LYS115 HIS116 PRO117 CYS118 TRP119 HIS120 CYS123 ASP124 CYS125 TYR126 CYS127 |
| | C4 | -7.1 | 72 | -1, 4, 10 | 20, 20, 20 | **Chain A**: CYS38 GLY39 PRO40 HIS42 ARG43 CYS44 TYR45 TYR46 CYS47 GLU52 CYS53 HIS54 LEU56 HIS57 ASP58 GLN59 CYS60 LYS61 HIS64 PRO65 CYS66 TYR67 |
| | C5 | -6.5 | 42 | 3, 6, 16 | 20, 20, 20 | **Chain A**: GLY32 HIS33 LYS34 SER35 ARG36 CYS38 GLY39 CYS44 TYR45 TYR46 CYS47 HIS48 GLU52 CYS53 HIS54 HIS55 LEU56 HIS57 ASP58 GLN59 HIS64 |

**Table S9.** Molecular docking results of sandaracopimaric acid with *Amphibalanus amphitrite* CP-20k-3

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-3 | C1 | -6.7 | 3269 | 1, -3, 1 | 26, 27, 30 | **Chain A**: CYS6 ASN7 PRO8 PRO11 ASN12 PHE13 ASN14 THR16 CYS19 ASP20 CYS21 ALA22 LEU24 PRO28 PRO29 ALA30 PHE31 PRO32 CYS33 PHE34 LEU36 SER45 CYS46 ASP47 CYS48 ASN49 LEU51 THR52 SER57 HIS58 CYS60 TRP61 THR63 ASP72 ASN73 ASN74 CYS75 ASP76 CYS77 ASP78 THR84 SER85 HIS86 PRO87 TYR89 HIS90 ARG91 GLN92 CYS93 |
| | C2 | -5.5 | 110 | 16, -1, -2 | 20, 20, 20 | **Chain A**: CYS19 ASP20 CYS21 ALA22 GLU23 LEU24 ARG25 CYS33 GLU41 THR42 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 HIS90 ARG91 GLN92 |
| | C3 | -5.5 | 107 | 19, 4, 4 | 20, 20, 20 | **Chain A**: ASP20 CYS21 ALA22 GLU23 LEU24 ARG25 PHE34 ARG35 LEU36 PRO37 SER38 GLY39 ASN40 GLU41 THR42 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 GLN50 TRP61 THR63 VAL65 LEU70 ARG91 |
| | C4 | -5.4 | 89 | 0, 4, -13 | 20, 20, 20 | **Chain A**: CYS1 LYS2 GLY3 PRO4 PRO5 CYS6 ASN10 PRO11 ASN12 PHE13 ASN14 THR16 SER18 LEU24 PRO28 PRO29 ALA30 PHE31 THR84 SER85 |
| | C5 | -5.8 | 63 | 16, 6, -4 | 20, 20, 20 | **Chain A**: GLY3 PRO4 PRO5 CYS6 ASN7 ASN12 GLU23 LEU24 ARG25 TYR26 CYS27 PRO28 PRO29 ALA30 PHE31 PRO32 CYS33 PHE34 ARG35 LEU36 PRO37 SER38 LEU51 |

**Table S10.** Molecular docking results of isopimaric acid with *Amphibalanus amphitrite* CP-20k-1

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-1 | C1 | -6.1 | 600 | 2, -1, 1 | 20, 20, 20 | **Chain A**: CYS39 ASP41 THR42 CYS43 ARG57 CYS58 GLU73 CYS74 ASN75 CYS76 ASN77 LEU79 THR80 SER85 HIS86 PRO87 CYS88 CYS105 ASP106 ILE112 ARG113 HIS114 PRO115 CYS116 TRP117 HIS118 ARG119 |
| | C2 | -6.2 | 357 | -8, 0, 11 | 20, 20, 20 | **Chain A**: ALA23 ARG24 GLY25 GLN26 LYS27 ARG28 ASN29 ASN31 ASN34 CYS36 ASP106 SER107 ILE108 GLU109 CYS110 SER111 ILE112 ARG113 CYS116 HIS118 GLU120 CYS121 GLY122 CYS123 |
| | C3 | -6.8 | 325 | 2, 9, 0 | 20, 20, 20 | **Chain A**: CYS30 PRO35 CYS36 PHE37 HIS38 CYS39 THR42 CYS43 ASP44 CYS45 SER46 SER47 GLU48 GLY49 LEU50 PHE51 CYS52 HIS56 VAL72 GLU73 CYS74 TRP117 GLY122 CYS123 ASN124 CYS125 HIS127 |
| | C4 | -5.7 | 113 | -5, 10, 15 | 20, 20, 20 | **Chain A**: CYS30 ASN31 PRO32 ASN34 PRO35 CYS36 PHE37 HIS38 SER47 GLU48 LEU50 GLY122 CYS123 ASN124 CYS125 THR126 HIS127 THR128 ALA129 |
| | C5 | -5.0 | 36 | 4, -8, -7 | 20, 20, 20 | **Chain A:** HIS60 ILE61 HIS62 VAL63 SER64 GLU73 ASN75 ASN77 HIS78 LEU79 THR80 PRO81 CYS82 ASP102 CYS103 ASP104 CYS105 ASP106 |

**Table S11.** Molecular docking results of isopimaric acid with *Amphibalanus amphitrite* CP-20k-2

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-2 | C1 | -7.6 | 6765 | 4, 1, -7 | 32, 27, 35 | **Chain A**: TYR49 ASP50 CYS51 GLU52 CYS60 LYS61 PRO62 PRO65 CYS66 TYR67 ARG68 LYS69 LEU70 PRO71 GLY72 SER73 ASP78 HIS81 VAL82 LYS83 CYS85 PRO90 TRP92 ASN93 LYS94 TYR95 THR96 VAL97 LYS98 HIS101 LYS102 GLN103 ARG104 ASN106 CYS107 HIS109 LEU110 LYS115 HIS116 PRO117 CYS118 TRP119 |
| | C2 | -6.2 | 391 | -5, -8, -15 | 20, 20, 20 | **Chain A**: CYS85 ASN86 HIS89 CYS91 LYS102 GLN103 ARG104 CYS105 ASN106 CYS107 ASP108 HIS109 LEU110 ARG111 CYS112 TRP119 HIS120 ARG121 HIS122 CYS123 CYS125 |
| | C3 | -6.5 | 89 | -8, -11, -7 | 20, 20, 20 | **Chain A**: GLN59 CYS60 LYS61 PRO62 CYS112 ASN113 ARG114 LYS115 HIS116 PRO117 CYS118 TRP119 HIS120 CYS123 ASP124 CYS125 TYR126 CYS127 LYS128 HIS129 |
| | C4 | -7.0 | 72 | -1, 4, 10 | 20, 20, 20 | **Chain A**: CYS38 GLY39 PRO40 HIS42 ARG43 CYS44 TYR45 TYR46 CYS47 CYS53 HIS54 HIS55 LEU56 HIS57 ASP58 GLN59 CYS60 LYS61 SER63 HIS64 PRO65 CYS66 TYR67 |
| | C5 | -6.8 | 42 | 3, 6, 16 | 20, 20, 20 | **Chain A**: HIS33 LYS34 SER35 ARG36 HIS37 CYS38 HIS42 ARG43 CYS44 TYR45 TYR46 CYS47 CYS53 HIS54 HIS55 LEU56 HIS57 ASP58 HIS64a |

**Table S12.** Molecular docking results of isopimaric acid with *Amphibalanus amphitrite* CP-20k-3

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-3 | C1 | -6.8 | 3269 | 1, -3, 1 | 26, 27, 30 | **Chain A**: ASN7 PRO8 ASN10 PRO11 ASN12 PHE13 CYS21 CYS27 PRO28 PRO29 ALA30 PHE31 PRO32 CYS33 PHE34 ARG35 CYS46 ASP47 CYS48 ASN49 LEU51 THR52 PRO53 ASP55 SER57 HIS58 TRP61 THR63 LEU70 ASP72 ASN73 ASN74 CYS75 ASP76 CYS77 ASP78 THR84 SER85 HIS86 PRO87 TYR89 HIS90 ARG91 |
| | C2 | -5.6 | 110 | 16, -1, -2 | 20, 20, 20 | **Chain A**: CYS19 ASP20 CYS21 ALA22 GLU23 LEU24 ARG25 ASN40 GLU41 THR42 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 HIS90 ARG91 GLN92 |
| | C3 | -5.5 | 107 | 19, 4, 4 | 20, 20, 20 | **Chain A**: CYS21 ALA22 LEU24 CYS27 PRO28 PRO29 PHE31 CYS33 PHE34 ARG35 LEU36 PRO37 SER38 ASN40 GLU41 THR42 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 TRP61 THR63 LEU70 ARG91 |
| | C4 | -5.6 | 89 | 0, 4, -13 | 20, 20, 20 | **Chain A**: CYS1 LYS2 GLY3 PRO4 PRO5 CYS6 ASN10 PRO11 ASN12 PHE13 ASN14 THR16 SER18 ASP20 LEU24 PRO28 ALA30 PHE31 THR84 SER85 |
| | C5 | -5.5 | 63 | 16, 6, -4 | 20, 20, 20 | **Chain A**: PRO4 PRO5 CYS6 ASN12 GLU23 LEU24 ARG25 TYR26 CYS27 PRO28 PRO29 ALA30 PHE31 PRO32 CYS33 PHE34 ARG35 LEU36 PRO37 SER38 LEU51 |

**Table S13.** Molecular docking results of pimaric acid with *Amphibalanus amphitrite* CP-20k-1

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-1 | C1 | -6.8 | 600 | 2, -1, 1 | 20, 20, 20 | **Chain A**: ARG57 CYS58 CYS76 LEU79 THR80 SER85 HIS86 PRO87 CYS88 CYS105 ILE112 ARG113 HIS114 PRO115 CYS116 TRP117 HIS118 |
| | C2 | -6.2 | 357 | -8, 0, 11 | 20, 20, 20 | **Chain A**: ALA23 ARG24 GLY25 GLN26 LYS27 ARG28 CYS36 CYS105 ASP106 SER107 ILE108 GLU109 CYS110 SER111 CYS116 HIS118 GLU120 CYS121 GLY122 CYS123 |
| | C3 | -7.3 | 325 | 2, 9, 0 | 20, 20, 20 | **Chain A**: CYS30 PRO35 CYS36 PHE37 HIS38 CYS39 GLN40 THR42 CYS43 ASP44 CYS45 SER46 SER47 GLU48 LEU50 HIS56 TRP117 CYS123 ASN124 CYS125 THR126 HIS127 |
| | C4 | -5.6 | 113 | -5, 10, 15 | 20, 20, 20 | **Chain A**: ASN29 CYS30 ASN31 PRO32 ASN34 PRO35 CYS36 PHE37 HIS38 SER47 GLU48 LEU50 GLY122 CYS123 CYS125 THR126 HIS127 THR128 ALA129 |
| | C5 | -4.9 | 36 | 4, -8, -7 | 20, 20, 20 | **Chain A:** HIS60 ILE61 HIS62 VAL63 ASN77 HIS78 LEU79 THR80 PRO81 CYS82 ASP83 TYR101 ASP102 CYS103 |

**Table S14.** Molecular docking results of pimaric acid with *Amphibalanus amphitrite* CP-20k-2

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-2 | C1 | -7.3 | 6765 | 4, 1, -7 | 32, 27, 35 | **Chain A**: CYS38 CYS44 TYR45 TYR46 CYS47 CYS51 CYS53 HIS54 HIS55 LEU56 HIS57 ASP58 GLN59 CYS60 LYS61 HIS64 PRO65 CYS66 TYR67 ARG68 VAL82 TRP92 ASN93 LYS94 TYR95 THR96 VAL97 LYS98 HIS101 LYS102 GLN103 ARG104 CYS105 ASN106 LEU110 LYS115 HIS116 PRO117 CYS118 |
| | C2 | -6.1 | 391 | -5, -8, -15 | 20, 20, 20 | **Chain A**: CYS85 ASN86 HIS89 PRO90 CYS91 LYS102 GLN103 ARG104 CYS105 ASN106 CYS107 ASP108 HIS109 LEU110 ARG111 CYS112 TRP119 HIS120 ARG121 HIS122 CYS123 ASP124 CYS125 |
| | C3 | -6.0 | 89 | -8, -11, -7 | 20, 20, 20 | **Chain A**: GLN59 PRO62 CYS112 ASN113 ARG114 LYS115 HIS116 PRO117 CYS118 TRP119 HIS120 CYS123 ASP124 CYS125 TYR126 CYS127 |
| | C4 | -7.0 | 72 | -1, 4, 10 | 20, 20, 20 | **Chain A**: CYS38 GLY39 PRO40 HIS42 ARG43 CYS44 TYR45 TYR46 CYS47 CYS53 HIS54 HIS55 LEU56 HIS57 ASP58 GLN59 CYS60 LYS61 HIS64 PRO65 CYS66 TYR67 |
| | C5 | -6.2 | 42 | 3, 6, 16 | 20, 20, 20 | **Chain A**: GLU25 GLY32 HIS33 LYS34 SER35 ARG36 HIS37 CYS38 GLY39 HIS42 CYS44 TYR45 TYR46 CYS47 GLU52 CYS53 HIS54 HIS55 LEU56 HIS57 ASP58 |

**Table S15.** Molecular docking results of pimaric acid with *Amphibalanus amphitrite* CP-20k-3

| Receptor (Protein) | CurPocket ID | Vina Score (kcal/mol) | Cavity Volume (Å$^3$) | Center (x, y, z) | Docking Size (x, y, z) | Contact Residues |
|---|---|---|---|---|---|---|
| *Amphibalanus amphitrite* CP-20k-3 | C1 | -6.6 | 3269 | 1, -3, 1 | 26, 27, 30 | **Chain A**: ASN7 PRO8 PRO11 ASN12 PHE13 ASN14 CYS15 THR16 SER18 ASP20 CYS21 GLU23 LEU24 PRO28 PRO29 ALA30 PHE31 PRO32 CYS33 PHE34 LEU51 THR52 HIS58 CYS60 TYR89 |
| | C2 | -5.3 | 110 | 16, -1, -2 | 20, 20, 20 | **Chain A**: CYS19 ASP20 CYS21 ALA22 GLU23 LEU24 ARG25 LEU36 ASN40 GLU41 THR42 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 HIS90 ARG91 GLN92 |
| | C3 | -5.2 | 107 | 19, 4, 4 | 20, 20, 20 | **Chain A**: ASP20 CYS21 ALA22 LEU24 PHE34 ARG35 LEU36 PRO37 SER38 GLY39 ASN40 GLU41 THR42 GLU43 PRO44 SER45 CYS46 ASP47 CYS48 ASN49 GLN50 TRP61 THR63 VAL65 LEU70 ARG91 |
| | C4 | -5.5 | 89 | 0, 4, -13 | 20, 20, 20 | **Chain A**: CYS1 LYS2 GLY3 PRO4 PRO5 CYS6 ASN10 PRO11 ASN12 PHE13 ASN14 THR16 LEU24 PRO28 ALA30 PHE31 THR84 SER85 |
| | C5 | -5.4 | 63 | 16, 6, -4 | 20, 20, 20 | **Chain A**: PRO4 PRO5 CYS6 ASN7 ASN12 GLU23 LEU24 ARG25 TYR26 CYS27 PRO28 PRO29 ALA30 PHE31 CYS33 PHE34 ARG35 LEU36 PRO37 LEU51 |

**ORCID:**
Levent Cavas: https://orcid.org/0000-0003-2136-6928
Ibrahim Kirkiz: https://orcid.org/0000-0002-1602-1901

*Journal of Life Sciences & Biomedicine, vol. 6(79), No 2, p. 33-45 (2024)*

# Zoology of Azerbaijan - yesterday and today

**Ilham Alekperov[*], Natalya Snegovaya, Elyana Tahirova**

*Institute of Zoology, Ministry of Science and Education of the Republic of Azerbaijan, 115 A.Abbaszadeh Str., 1128 Pass., 504 Block, AZ1004, Baku, Azerbaijan*

[*]***For correspondence:*** *i_alekperov@yahoo.com*

Received: September 17, 2024; Received in revised form: October 10, 2024; Accepted: November 18, 2024

**The article presents information on the study of the species diversity of various animal groups in Azerbaijan, from protozoans to mammals. Main publications on each studied group and the great contributions of Azerbaijani zoologists to the study of the fauna and general species diversity of Caucasus are emphasized.**

***Keywords****: Fauna, species diversity, Azerbaijan, investigation*

## INTRODUCTION

When we are talking about the study of the animal kingdom, we often experience that not only non-specialists but also many biologists confuse concepts such as fauna, and more fashionable in recent years species diversity. The term fauna is used to define the community of animals living in a certain territory. The concept of fauna includes both systematic and geographical content. Consequently, fauna is a historically formed community of animal species living in a certain territory. It is known that the fauna of any territory consists of different faunistic complexes, which combine species with similar habitats. The term species diversity is broader and as an indicator reflects not only qualitative, i.e. species composition of the biocenosis, but also quantitative relationships between species. The more species diversity of biocenosis and the more highly branched food chains, the more sustainable the ecosystem. Because different species can substitute each other in food chains.

Overall, scientists (Zhang, 2013) have described just over 1.6 million animal species (including more than 133 thousand fossil species), most of which are arthropods (more than 1.3 million species, 78%), mollusks (more than 118 thousand species) and vertebrates (more than 42 thousand species) According to the projections, considering the still extremely poor study of many animal groups in most regions of the globe, the total number of animal species is estimated at 5-30 million, and some experts cite figures of up to 80 million or more. Although the International Union for Conservation of Nature officially records the extinction of only 777 species as a result of human activity, some experts believe that this estimate is true for only 5% of known species. According to the latest data from 2022 in the journal Biological Reviews, between 150,000 and 260,000 animal species have become extinct over the past 5 centuries. Apparently, there is a big spread in quantitative estimates. It is clear that our knowledge today is still extremely poor and to talk about sufficient study of the animal world, especially about representatives of most groups of invertebrates is completely wrong. All of the above is also true for the fauna of the Caucasus. The South Caucasus region has always been interesting for researchers since ancient times, as the whole region of the Caucasus is considered one of the centers of speciation on the Earth. Naturalists and travelers have been interested in the wildlife of Azerbaijan since ancient times. Listing of various animal species, as well as their descriptions, can be found in the works of ancient Greek, Roman and Arabic scientists. However, all this is not zoology yet, but only the initial accumulation of information about animals.

Zoology, which stadies animals, is one of the classical biological sciences. Its founder, as well as a number of other sciences, is considered to be

https://doi.org/10.59849/2710-4915.2024.2.33
Available online 31 December 2024

Aristotle, the great scientist and thinker of Ancient Greece (4th century BC). He first systematized accumulated knowledge about animals and divided all known species into two groups - animals with blood and animals without blood. The first group included vertebrates, the second – invertebrates. Later, K.Linnaeus (1735) was the first to offer classification of all living organisms based on binomial nomenclature, which is still used by biologists all over the world.

The first fragmentary information about the animal kingdom of Azerbaijan, mainly amphibians and reptiles, is found in the works of the German traveler, professor of botany at the University of St. Petersburg S.Gmelin (1744-1774). Some of his scientific works were published after his death processed by Pallas (1741-1811), a famous German scientist and encyclopedist who worked in Russia. The first truly scientific observations of birds and mammals appeared in the zoological works of G.Radde (1884, 1899) He was the founder and director of the Caucasian Natural History Museum (Tiflis), for which he personally gathered a large collection of faunistic material. Radde played a major role in the further development of zoological research in Azerbaijan.

At a later time, towards the beginning of the 20th century and after the establishment of the Soviet government in Azerbaijan, new researchers, prominent Russian and Soviet scientists, such as N.Y.Dinnik, K.A.Satunin, B.S.Vinogradov, O.A.Grimm, A.N.Derzhavin, N.K.Vereshchagin and others appeared. This period of development of zoology, scientific achievements and contribution of scientists to the study of the Azerbaijan fauna are covered in detail in the works of Azerbaijani scientists R.D.Jafarov (1948,1949), monographs of A.G.Kasimov (1965,1972), S.M.Asadov (1960), M.A.Musayev, A.M.Veysov (1965), Kh.M.Alekperov (1966), Y.A.Abdurahmanov, and A.M.Alekperov (1978). These scientists themselves also did a lot for the development of zoology in Azerbaijan and trained a number of highly qualified national personnel.

During the years of independence of Azerbaijan, the collective of scientists of the Institute of Zoology conducted fundamental research on the biodiversity of the most diverse groups of the fauna of the republic.

The protistologists of the institute conducted extensive research on the species composition of single-celled parasites - coccidia, their life cycles, cytochemistry and biochemical aspects of the relationship between the parasite and the host. As a result of their research, 250 species of protozoan parasites were found, belonging to the genera Leishmania, Trypanosoma, Eimeria, Isospora, Cryptosporidium, etc. More than 80 species of coccidia were described for the first time new to science. In most regions of Azerbaijan, Eimeria, Sarcosporidia, Cryptosporidium parasitizing wild animals and birds, their species composition, host specificity were studied, and the routes of invasion were identified. The results of fundamental research were proposed for implementation in production for the diagnosis and prevention of eimeriosis in domestic animals and birds in agriculture.

Investigations on free-living protozoa in Azerbaijan began in the 60-70s of the XX century, but with the use of required modern cytological methods only since the 80s of the last century. For the first time in science, 1 genus and 40 species of ciliates were found in the Caspian Sea (Agamaliev, 1983), but subsequent studies of sea and freshwaters, as well as the soils of Azerbaijan, showed that the species diversity of free-living protozoa inhabiting them is incomparably greater. During the years of Azerbaijan's independence, for the first time, 3 families, 12 genera and more than 130 species of free-living ciliates new to science have been described for the first time (Alekperov, 2005, 2012).

Intensive study of another ecologically important group of free-living protozoa - testate amoebae has also begun. In recent years, 2 families, 7 genera and 70 species of testate amoebae have been found and described for the first time new to science in the fresh waters of Azerbaijan. The summarized results of the research on free-living ciliates and testate amoebae were published in English and Russian as the first cadastre in Azerbaijan, which provides data on 757 species of ciliates and 265 species of testate amoebae for the fauna of the republic (Alekperov et al., 2017).

It is known that free-living protozoa, especially ciliates, play an important role in nature in the self-purification of marine and fresh water bodies. Feeding on large quantities of bacteria,

including pathogenic species, ciliates contribute to the rapid self-purification of marine and fresh waters. In addition, ciliates quickly respond to the slightest changes in the environment. The developed method of bioindication of the degree of environmental pollution using free-living ciliates is based on this feature of protozoans (Alekperov, 2023) At present, this modified method allows biotesting the degree of organic pollution of sea and fresh waters, as well as soils of Azerbaijan. In addition, biotesting through ciliates makes it possible to use them to assess the toxicity of pollution with oil, a number of heavy metals and some insecticides simultaneously at the cellular-organismal and population levels. Azerbaijani parasitologists have found more than 400 species of helminths in the fish in different fresh water bodies of the republic, of which 2 genera and 25 species were described as new to science for the first time (Mikailov, 1975).

In all major water bodies of Azerbaijan, including the Caspian Sea, the species composition of fish parasites was studied, investigations of the fauna, ecology and zoogeography were carried out, the morphology, systematics and biology of the main parasites of aquatic animals were studied (Ibrahimov, 2012). A comprehensive study of the infection of freshwater mollusks, which are intermediate hosts of trematodes was conducted, and based on a study of the morphology of the cercaria stage, a number of new species of trematodes were described (Manafov, 2010) Azerbaijani helminthologists have carried out large-scale research in the Kura-Aras lowland, Sheki-Zagatala and Absheron-Gobustan zones of Azerbaijan, where the species diversity of pathogens causing fascioliasis, dicrocelliosis, protostrongyliosis, echinococcosis, haemonchosis and binostomosis was studied in farm animals (Sadikhov, 1962; Feyzullaev, 1971; Fataliyev, 1975). The helminths' fauna of game birds has been studied (Vaidova, 1978), and the role of stray cats and dogs in the spread of helminths has been investigated (Ibrahimova, 2021). More than 400 species of plant-parasitic nematodes have been found, 95 of which are considered to cause serious damage to horticulture.

Together with veterinary specialists, a zoning of the distribution of helminthiasis was carried out, a distribution map was compiled, and 25 practical recommendations were proposed for implementation in farms.

Hydrobiologists of our institute made a great contribution to the study of the fauna and species diversity of hydrobionts (zooplankton, zoobenthos, periphyton) of the sea and fresh waters of Azerbaijan. A number of the most important fresh water bodies of the republic were studied, including reservoirs, that were created at a later time, and reservoirs of Absheron and Guba-Khachmaz region, which made it possible to identify several species new to the fauna of the Caucasus and Azerbaijan (Kasimov, 1972) Much attention was also paid to the Caspian Sea research, as a result of which the hydrofauna and ecology of the Azerbaijan sector of the Caspian Sea were studied comprehensively. The Caspian plankton has been studied in detail (Kasimov, 2004). It is known that the most numerous and characteristic group of the animals with a large species diversity is arthropods. According to estimates of various experts, there are more than 1.5 million species of insects in the world. In Azerbaijan, research on various groups of arthropods has been carried out for a long time. Over the years of the existence of the Institute of Zoology, Azerbaijani scientists have made a huge contribution to world zoology. At present, thanks to many years of research by Azerbaijani scientists, about 25 thousand species of insects and 1100 species of arachnids have been identified in the fauna of Azerbaijan.

In Azerbaijan, the first studies of ticks - carriers of piroplasmosis of productive livestock were conducted in 1930-1935 of the last century. However, systematic research of the fauna, biology, ecology and economic importance of the broad class of arachnids began only after the formation of the Institute of Zoology. The aim was to study the fauna of separated groups of arachnids in Azerbaijan and identify patterns of their distribution in various natural and climatic zones of the republic. The research primarily covered ixodid ticks. The first large-scale arachnological research in Azerbaijan was carried out by A.Hajiyev (1983) on the study of ixodid and gamasid ticks, covering all ecological groups of gamasids living on plants, parasites of rodents, insectivores, bats, reptiles, and birds. In total, the fauna of gamasid mites of Azerbaijan identified by Hajiyev is represented by 152 species of 15

families, of which 8 species were noted for the first time new to the fauna of the USSR. The faunal complex of gamasid mites, the distribution of ticks in landscape-ecological zones were also identified, the relationships of gamasids with habitats were analyzed, etc. One of the important directions of parasitological research is the identification and study of ectoparasite complexes of separated groups of animals. On the initiative of Hajiyev, a series of studies were carried out to study the ectoparasite complexes of separated groups of animals, thanks to which the patterns of formation of the ectoparasitic fauna of various groups of animals were traced. The results of the research were widely implemented in the national economy, including measures to protect the population from parasitic arthropods. The complex of ectoparasites of bats in Azerbaijan was studied by T.Dubovchenko (1968). It was revealed that bats are parasitized by 90 species of ectoparasites (various groups of ticks and insects) 4 species of red mites were described as new to science, and 6 species of mites were noted for the first time for the fauna of the USSR and 30 species of ectoparasites for the fauna of Azerbaijan.

In Azerbaijan, the first studies of ticks that carry piroplasmosis in farm animals are associated with the name of N. Abusalimov (1963). He established the species composition of ixodid ticks parasitizing on farm animals, as well as the role of different species as carriers of these described diseases. Along with studying the fauna and bioecology of ixodid ticks, in subsequent years he studied the fauna and biology of argasid ticks of Azerbaijan, including 10 species from 3 genera. In the mid-60s of the last century, intensive study of the fauna of beneficial phytoseiid mites began. E.Abbasova (1972) studied predatory phytoseiid mites, natural enemies of numerous plant pests. It was established that the fauna of phytoseiids of Azerbaijan includes 56 species, of which 12 species were described as new to science, and 51 species were described for the first time for the fauna of Azerbaijan. Tetranychid mites were studied by V.Zapletina, Z.Musayeva, O.Aslanov, S.Khalilova, L.Mehtiyeva. About 100 species of tetranychid mites are known in Azerbaijan, many of which are serious pests of agricultural crops. The fauna of tetranychid mites of the Lesser Caucasus within Azerbaijan is represented by 50 species, of which 1 species is described as new to science, 20 species as new to the fauna of the republic. The fauna of acariphages of the studied region includes 47 species, of which 1 species is described as new to science, 14 are new to the fauna of the Caucasus, 13 are new to Azerbaijan fauna. Azerbaijani acarologists also studied the predatory mites Prostigmata (Aslanov, Musayeva, 2001) As a result of their research, 94 species from 16 families were identified, of which 4 families, 18 genera and 44 species were identified as new to the fauna of the Caucasus, 6 families, 23 genera and 29 species are new to the fauna of Azerbaijan.

Systematic and complete study of spiders of Azerbaijan was started by P. Dunin (1984, 1992) in the last century. He recorded a total of 457 species for the local fauna, of which 26 species and 2 genera were described for the first time new to science. Further studies of the spider fauna of Azerbaijan, as well as their biology, were carried out by the young researcher E.Huseynov, who unfortunately died untimely (Huseynov et al., 2005; Huseynov, 2014). He described 1 genus and 25 species new to science. Summarizing the data of these authors, we can assume that the spider fauna of Azerbaijan currently includes about 700 species belonging to 268 genera and 43 families. However, this is not a complete list of the species diversity of this huge group of Azerbaijan fauna. At present, young specialists - T.Nuruyeva and Sh.Khasayeva - are successfully studying spiders. Recently, T.Nuruyeva (Nuruyeva and Huseynov, 2021; Nuruyeva et al., 2024) has described 4 species new to science, and 19 species new to fauna of the Caucasus.

N. Snegovaya conducts a systematic, long-term study of the order Opiliones, both in Azerbaijan and internationally, in collaboration with colleagues from other countries. She described 6 genera and more than 50 new species of opiliones new to science from the regions of the Caucasus, Kazakhstan and Middle Asia, Turkey, Africa and other regions (Snegovaya, 2010, 2014). The first studies of the fauna of the most ancient order of arachnids, scorpions of Azerbaijan, were carried out by E.Yusubov (1984). He studied the distribution areas of 3 known scorpion species in the republic, identified geographic populations of the mottled scorpion, revealed their useful role in biocenoses as active predators, and studied the

development and reproduction of scorpions. The current state of scorpions and solifuges in Azerbaijan is studied in detail by N.Novruzov (2023). He summarized the information on the fauna, taxonomy, morphology and distribution of scorpions and solifuges in the South Caucasus. Pseudoscorpions, a small order of arachnids in species composition were studied in Azerbaijan by S. Dashdamirov (Dashdamirov, 1988, 1991). According to his research, the fauna of pseudoscorpions in the Caucasus includes 52 species, of which 24 species were described by him for the first time new to science.

A.Bogachev, one of the first researchers and organizers of works on entomology, made a great contribution to the development of native entomology. The chapter on entomology in the book "The Fauna of Azerbaijan" (1951), edited by Bogachev, which provides information on many groups of insects in the country at that time and at present, is of great importance.

The development of Azerbaijani entomology is inextricably linked with the scientific activities of Corresponding Member of the Academy of Sciences of Azerbaijan N.Samedov. He made a huge contribution to the development of such fields of zoology as general entomology, soil zoology, biocenology and plant protection.

Since the 60s of the last century, research has been conducted on the study of soil insects and other invertebrates. Collembola or springtails were studied within the framework of the soil research program by Z.Rasulova (1980, 1982). More than 180 species of collembola were identified in Azerbaijan, of which 8 species were described for the first time for the fauna of the USSR, 15 species - for the fauna of the Caucasus, and 11 species - for science.

Since 2013, systematic research has been conducted by N.Snegovaya (Snegovaya, 2023), to study the faunal composition of dragonflies in Azerbaijan. 70 species of dragonflies belonging to 10 families were found, and the total number of species, including literary data and collection materials, is 72 species, of which 22 species are noted for the first time for the fauna of Azerbaijan. The order Hemiptera or true bugs is widely distributed in Azerbaijan and has about 1000 species. The order was studied by D.Hidayatov (1982), I.Drapolyuk (1982), A.Atakishiyeva (1988).

It is known that butterflies are an extremely numerous groups of insects with complete metamorphosis, that are diverse in size, color and lifestyle. According to the number of known species, butterflies are second after the beetles. In Azerbaijan, the total number of lepidopteran species is no less than 4,500 belonging to 82 families. The noctuid moth family has been studied for a long time by academician S.Aliyev in Azerbaijan, rich in the species (2016). He found 716 species of moths, studied their distribution in different regions of the republic, food relationships, identified pests of agricultural plants, and against a serious cotton pest, an integrated method of biological control was proposed and implemented. As higher butterflies papilionoids were systematically studied over a long period of time by Effendi R., the result of his research was the identification of a species composition that included 457 species, of which 213 belong to the papilionoids, and 2 species new to science were described (Effendi, 1971). Z.Mamedov (2004) studied harmful lepidopterans that damage fruit crops in Azerbaijan and identified their parasites. As a result of long-term research, he identified 74 species of lepidopterans – pests of fruit plants, of which 16 species were noted for the first time in the fauna of Azerbaijan. The systematic study of bees in Azerbaijan was first started by Kh.Aliyev. During the period of research, he studied the fauna and ecology of bees in the republic. In general, 642 species of bees were recorded by him, of which 316 species were noted for the first time in the fauna of the republic and 154 for the first time in the Caucasus; the distribution of bees in landscapes and natural areas was studied (Aliyev, 2010). Bees of the Halictidae family are one of the numerous and species-rich families. According to the research of G.Huseynzade (2001), the family includes 126 species from 13 genera, of which 57 species were recorded for the first time in the fauna of Azerbaijan. Trophic relationships and phenology within this family were studied for the first time. A systematic study of ground beetles (Carabidae), as well as different representatives of this family that are harmful to agricultural crops, was conducted by Corresponding Member of the ANAS N.Samedov. He studied harmful ground beetles of the genus *Zabrus* in Azerbaijan, and in

his book (1954), 295 species of ground beetles are indicated for the Azerbaijan fauna, a list and description of 14 species of ground beetles that are harmful to agricultural crops are provided. Apart from ground beetles, N.Samedov (1963) also actively studied another family of beetles – longhorn beetles. In total, he recorded 204 species for the fauna of Azerbaijan. The study of leaf beetles was conducted by N.Mirzoyeva (1988). For the fauna of Azerbaijan, she identified 400 species of beetles, of which 1 species was described as new to science, 133 new to the fauna of Azerbaijan.

Diptera occupy an important place among the numerous orders of the insect class of the number of species and the diversity of their representatives. In Azerbaijan, the number of dipteran species is more than 2000. This group was studied by Sh.Jafarov (Jafarov, 1962), G.Nagiyev (Nagiyev, 1962), G.Trofimov (Trofimov, 1971) and other researchers.

In 1971, the Laboratory of Ecology and Physiology of Insects was established. The laboratory staff carried out a large number of experimental works. B. Ahmadov studied the ecological regulation of seasonal cycles of aphids that harm cotton, created optimal conditions for development and reproduction, thermal thresholds and photoperiodism of cotton aphids and alfalfa aphids.

Research in the field of insect biochemistry, the results of which are important in assessing the physiological state of the insect organism, and in the development of effective measures to combat pests of agricultural crops, was carried out for many years by H.Guliyeva. Her research on the ecology, physiology and biochemical characteristics of various life stages of pests of agricultural plants helped to increase the effectiveness of biological methods.

The Braconidae family was studied by A.Abdinbekova (1975). According to her results, the fauna of Braconidae in Azerbaijan includes 523 species belonging to 88 genera, of which 38 species were described for the first time for science, more than 150 new ones for the fauna of Azerbaijan. The distribution patterns of Braconidae by natural-climatic regions of the republic, their relationships with hosts and flowering vegetation were established. Recently, a modern study of antlions (Myrmeleontidae) of Azerbaijan, including the use of molecular biology methods was carried out by I.Kerimova. As a result of her research, the fauna of these insects currently includes 60 species (Kerimova, 2019, Kerimova, Krivokhatsky, 2018). E.Huseynova is studying the fauna, ecology and economic importance of jewel beetles (Buprestidae) (Huseynova, 2013). Much attention at the Institute of Zoology has always been paid to the study of entomophages and the theoretical foundations of biomethods of plant protection, the objectives of which were to identify the species composition of entomophages (predators and parasites), study their biological and ecological characteristics, the degree of their infestation by various host-pests, identify the most effective species that play a significant role in reducing the number of major agricultural pests, as well as develop methods for mass reproduction and their implementation in production.

All long-term research of A.Aliyev (1983) was completely devoted to the study of the possibilities of using various species of entomophagous as biocontrol agents against agricultural pests. Since the 60s of the last century, he has been studying beneficial insects and conducting a fundamental study of the fauna and taxonomy of parasitic ichneumonids. As a result of these studies, 600 species of 165 genera of ichneumonids were identified, their distribution was determined, and 2 species were described as new to science. The main scientific direction of L.Rzayeva's research (1986) was the study of Chalcididae - a group of insects that play an important role in reducing the number of agricultural pests. The species composition of Chalcididae was identified, including 472 species, of which 150 species were presented for the first time for the fauna of the Caucasus. G.A.Mustafayeva (2020) was the first who comprehensively studied Coccoidea and Coccidae insects. As a result of her research, 33 species of Coccoidea insects belonging to 21 genera and 19 species of Coccidae insects belonging to 9 genera were identified, of which 11 and 8 species are new to Azerbaijan fauna, respectively.

As can be seen from our brief review of taxonomic and faunistic works, Azerbaijani zoologists have made a significant contribution to the study of animal diversity not only in the republic but also in other regions of the globe. At

present, it is urgently necessary to conduct a revision of the fauna of various groups of the animal kingdom, to assemble all known fragmentary data on various taxa, taking into account the modern requirements of their taxonomy. It is necessary to create cadastres for each group of the animal kingdom of Azerbaijan. The first step in this huge work is the compilation of checklists, based on the summation of all previously known publications, museum materials and own modern results. Recently, much work has been done by N.Snegovaya on compiling checklists for different groups of insects, such as butterflies (Lepidoptera, Rhopalocera) (Snegovaya, Petrov, 2019), sphinx moths (Sphingidae) (Snegovaya, Petrov, 2021), crane flies (Diptera, Tipuloidea) (Snegovaya, 2021), ants (Formicidae) (Snegovaya, Shigayev, 2022), orthopterans (Orthoptera) (Snegovaya, Kerimova, 2022), water beetles (Coleoptera: Adephaga, Polyphaga) (Snegovaya, Shirinova, 2022), noctuids (Lepidoptera: Erebidae, Nolidae, Euteliidae, Noctuidae) (Snegovaya, Matov, 2024), geometrid moths (Geometridae) (Snegovaya, 2024). Work on creating checklists is ongoing.

Ichthyological research in Azerbaijan has been conducted since the beginning of the 20th century. Among these works, “Sevruga: a biological essay” (1922) and “Reproduction of sturgeon stocks” (1947) should be noted, which laid the foundation for ichthyological research in Azerbaijan. Later, Y. Abdurakhmanov developed and increased them, having studied the species diversity, ecological characteristics and reproduction biology of fish in Azerbaijan. The results of these studies were summarized in his monographs "Fishes of Azerbaijan" (1955) and "Freshwater Fishes of Azerbaijan" (1962). More recent data on ichthyological research in Azerbaijan are presented in the publications of H.Abbasov “Biology of juveniles of the main commercial fish species (perch, carp) of Azerbaijan” (1972) and Z.Kuliyev “Fishes of the Greater and Lesser Gyzylaghaj Bays of the Caspian Sea” (1989). The latest ichthyological research was conducted by N.Mustafayev (Mustafayev, 2024a, 2024b).

Based on the research of Azerbaijani herpetologists, the modern fauna of Azerbaijan includes 63 species of reptiles and 12 species of amphibians. (Jafarov, 1949; Aliyev, 1974; Akhmedov et al., 2015). In addition, new habitats of lizard species listed in the Red Book of Azerbaijan - the *Trapelus ruderatus* and *Phrynocephalus persicus* were found for the first time in the Lerik region. The current range of another species of lizard, also listed in the Red Book of Azerbaijan, *Phrynocephalus horvathi*, has been clarified, and new habitats of the rare southern crested newt have been identified. Important results obtained by herpetologists include the first discovery of the species *Vipera lotievi* (Iskenderov et al., 2017), and lizards of the genus Podarcis for the fauna of Azerbaijan (Oskyrko, Iskenderov et al., 2022). Azerbaijani ornithologists have made a significant contribution to the study of the bird fauna of the republic. Among them, the works of such scientists as Gambarov (1941), Tuayev (2000), Khanmammadov (1971), Mustafayev (1993), Patrikeev (2004) should be noted. The latest major reports on the birds of Azerbaijan include the recently published abroad collective work “European Breeding Birds Atlas 2” (Sultanov et al., 2020), which also includes a section on birds from Azerbaijan fauna. A number of endemic species, such as the Caucasian grouse and Caucasian snowcock, which are on the brink of extinction, are protected by the government. The status of 45 other rare and endangered bird species has been clarified (Karimov, 2021). Data on 25 species of birds of the avifauna of Azerbaijan have been prepared and transferred for inclusion in the list of species protected by CITES. Due to the threat of bird flu, on behalf of the Ministry of Ecology and Natural Resources, ornithologists of the Institute of Zoology have identified and mapped the main places of accumulation of waterfowl in the republic (Babayev, 1990, 1991).

During the years of Azerbaijan's independence, mammalogists of the Institute of Zoology have identified 115 species of mammals, including 13 species of insectivores and 33 species of bats. Based on long-term observations, 42 species from different groups were included in the Red Book of Azerbaijan. Bioecological studies were conducted on various groups of mammals of the fauna of Azerbaijan and their results were published in the monograph "Mammals of South-Western Azerbaijan" (Alekperov, 1966).

The results of many years of research by I.Rahmatulina (2005) were published in her fundamental monograph "Bats of Azerbaijan", which provides an up-to-date overview of the fauna of this group, including rare and endangered species, their ecology and zoogeography. In 2006-2010, theriologists developed a plan for the reintroduction of goitered gazelles in Azerbaijan. In this work, areas were selected in the lowland and foothill regions of Azerbaijan for population with goitered gazelles caught in the Shirvan zone (Kuliyev, 2018) The program of reintroduction of goitered gazelles presented to the Ministry of Ecology and Natural Resources with the financial support of the Heydar Aliyev Foundation and the World Wildlife Fund was successfully implemented. The modern fauna of the Nakhchivan Autonomous Republic is successfully studied by the staff of the Institute of Bioresources (Talibov, 1999; Talibov et al., 2016; Talibov, 2021).

Currently, 1,500 species of parasitic and free-living protozoa, about 1,200 species of parasitic worms, including 400 species of phytohelminths, 290 rotifers, 360 species of crustaceans, about 25 thousand insects, 1,100 arachnids, more than 180 species of mollusks, 101 species of fish, 11 species of amphibians, 54 species of reptiles, 365 species of birds and 113 species of mammals have been identified in the fauna of Azerbaijan.

The successes of zoologists during the years of Azerbaijan's independence are reflected in the number of scientific descriptions of animal species new to science. For example, over the last 30 years, 210 species of parasitic and free-living protozoa, 60 species of helminths, 46 ticks, 17 species of pseudoscorpions, more than 50 species of spiders and 60 harvestmen, 121 species of insects and 2 species of amphipods have been described. Most of these descriptions have already been included in international catalogues and are recognized by reputable specialists in different countries.

Over the years of independence, international cooperation with scientists from Western Europe and the United States has developed particularly well. During this time, scientists from the Institute of Zoology have received more than 25 grants from various international funds to conduct joint scientific research with colleagues from the United States, France, Finland, Germany, the Czech Republic, Poland, Bulgaria and Turkey. Some of this scientific research continues today. An indicator of the high professionalism of Azerbaijani zoologists is their participation and membership in international organizations. For example, Doctor of Biological Sciences N.Snegovaya is a member of the American Society of Arachnologists. A number of scientists from the Institute of Zoology are members of the editorial board of some foreign journals or experts in international programs (I.Alekperov, N.Snegovaya, I.Kerimova, Sh.Ibrahimov, T.Kerimov, etc.).

During the period of national independence of Azerbaijan, the staff of the Institute of Zoology made a great contribution not only to the development of fundamental zoology but also actively participated in the implementation of the Presidential State Programs, including the 2004-2015 program of socio-economic development of the regions of the republic, employment strategy, support for entrepreneurship, sustainable provision of the population with food products, sustainable development, food security and conservation of biodiversity. Based on the scientific work carried out at the institute, the results of the following studies were presented for implementation:

1. Study of the biodiversity of water bodies of Azerbaijan.
2. Ensuring sustainable development of biological resources.
3. Organization of aquaculture in the Caspian.
4. Creation of river and lake fish farms.
5. Creation of a system of measures for biological control of insect pests of agricultural crops using local and acclimatized entomophages.
6. Development of methods of controlling protozoal and helminthic diseases of farm animals and their implementation in practice.

For each government decree, the institute proposed 6 proposals for implementation. In addition, at present, information on more than 500 species of animals of the Azerbaijan fauna has been prepared for posting on the website of the institute, which after its opening is very popular not only among domestic and foreign scientists but also among the population of Azerbaijan. Together with the Ministry of Ecology and Natural Resources of

Azerbaijan, the National Academy of Sciences, being the first executor, participated in the preparation of the 2nd and 3rd editions of the "Red Book" of Azerbaijan, in which the section on the fauna, including information on 213 species of animals, was completely prepared by the colleagues of the Institute of Zoology.

The zoomuseum operating at the Institute of Zoology successfully advanced during the period of independence of Azerbaijan. Currently, the Zoological Museum is the national scientific demonstration fund of the Republic, which has collected about 2,000 exhibits of stuffed animals and skeletons: 270 species of vertebrate animals and 625 exhibits of arthropods belonging to 400 species.

About 5 thousand local and foreign guests visit the museum every year. The employees of the museum, along with the work directly related to the activities of the museum, participate in the research of the Institute of Zoology, conducting morphological, taxonomic and ecological studies of various groups of animals.

In addition to the exhibits displayed in the museum expositions, each laboratory of the Institute of Zoology has its own collection, which preserves total preparations, including holotypes and paratypes, more than 600 species of parasitic and free-living protozoa, 1400 species of helminth parasites of humans, animals and plants, about 10 thousand exhibits of 3109 species of aquatic invertebrates, about 100 thousand exhibits of 20,000 species of arthropods, 145 preserved specimens of 43 species of fish, 305 exhibits of 13 species of amphibians, 968 exhibits of 40 species of reptiles, 15,000 stuffed animals and skeletons of 582 species of birds, about 12,200 stuffed animals and skeletons of 84 species of mammals.

Besides representatives of the local fauna, the collection fund of the Institute of Zoology also has exhibits of animals from many countries of the world, obtained as a result of scientific exchange or collected on the initiative by employees of the Institute of Zoology during scientific visits abroad.

It should be noted that the international relationship of our scientists, which has increased during the period of Azerbaijan's independence, contributes to the increase and constant updating of the collection materials of the Institute of Zoology. Rich collection materials reflect the enormous biodiversity and genetic fund of the Azerbaijan fauna.

The Institute's long-term plan includes such challenges as studying the biodiversity of the animal kingdom, especially, poorly studied groups of animals; clarifying the taxonomy of some genera and species; studying the biology and ecology of economically important, rare and endangered species; developing technology for breeding and reintroducing useful animals; clarifying parasite-host relationships, intraspecific variability using biochemical and molecular genetic methods; studying the influence of increasing anthropogenic factors on the distribution, number and behavior of animals in various natural complexes.

## REFERENCES

**Abbasov H.** (1972) Biology of juveniles of the main commercial fish species (perch, carp) of Azerbaijan. *Abstract of dissertation for candidate of biological sciences*. Baku, 52 p. (in Russian).

**Abbasova E.D.** (1972) Phytoseid ticks of Azerbaijan. *Abstract of dissertation for candidate of biological sciences*, Baku, 26 p. (in Russian).

**Abdinbekova A.A.** (1975) Braconids (*Hymenoptera, Braconidae*) of Azerbaijan. Baku: Elm, 322 p. (in Russian).

**Abdurahmanov Y.A.** (1962) Freshwater fishes of Azerbaijan. Baku: Publishing House of the Academy of Sciences of the Azerbaijan SSR, 434 p. (in Russian).

**Abusalimov N.S.** (1963) Ixodid ticks and haemosporidioses of farm animals. Baku: 123 p. (in Russian).

**Agamaliev F.G.** (1983) Ciliates of the Caspian Sea: taxonomy, ecology, zoogeography. Leningrad: Nauka, 232 p. (in Russian).

**Akhmedov S.B., Novruzov N.E., Bunyatova S.N., Gasimova G.Kh.** (2015) On the study of herpetofauna (Amphibia: Anura, Reptilia: testudines', Sauria, Serpentes) of biocenoses of the Divichi firth of the Caspian Sea. *Bulletin of MGOU, series Natural sciences*, **4:** 6-15 (in Russian).

**Alekperov A.M.** (1978) Amphibians and reptiles of Azerbaijan. Baku: Elm, 260 p. (in Russian).

**Alekperov I.Kh.** (2005) Atlas of free-living

ciliates (classes *Kinetofragminophora, Colpodea, Oligohymenophora, Polyhymenophora*) Baku: Borchaly, 310 p. (in Russian).

**Alekperov I.Kh.** (2012) Free-living ciliates of Azerbaijan (ecology, zoogeography, practical significance) Baku: Elm, 520 p. (in Russian).

**Alekperov I.Kh.** (2023) Free-living ciliates and their use in environmental biotesting. Moscow: KMK Publishing House, 140 p. (in Russian).

**Alekperov I.Kh. Snegovaya N.Yu. Tahirova E.N.** (2017) Cadastre of free-living ciliates and testate amoebae of Azerbaijan. Moscow: KMK Publishing House, 126 p. (in Russian).

**Alekperov Kh.M.** (1966) Mammals of southwestern Azerbaijan. Baku: Publishing House of the Academy of Sciences of the Azerbaijan SSR, 150 p. (in Russian).

**Aliyev A.A.** (1983) Results of insect research and their use in biological control of harmful insects. *Proceedings of the symposium "Beneficial insects and their protection in Azerbaijan"*. Baku: pp. 3-11 (in Russian).

**Aliyev Kh.A.** (2010) Bees (*Hymenoptera, Apoidea*) of Azerbaijan. *Abstract of doctoral dissertation*. 50 p. (in Russian).

**Aliyev S.V.** (2016) Fauna, distribution and bioecological features of Azerbaijan noctuids (*Lepidoptera, Noctuidae*) Baku: Elm. 412 p. (in Russian).

**Aliyev T.A.** (1974) Venomous snakes of Azerbaijan: (Ecological and faunistic study) Abstract of a dissertation for the degree of candidate of biological sciences. Baku: 21 p. (in Russian).

**Asadov S.M.** (1960) Helminth fauna of ruminants of the USSR and its eco-geographical analysis. Baku, Publ. of the Academy of Sciences of the Azerbaijan SSR, 510 p. (in Russian).

**Aslanov O., Musayeva Z**. (2001) On the study of actinedid mites (Acariformes: Actinedida) of Azerbaijan. *In the collection: "Study and protection of animals at the end of the 20th century*". Baku: Elm, pp. 209-211 (in Russian).

**Atakishiyeva A.M.** (1988) Bugs of the subfamily *Mirinae* (*Heteroptera, Miridae*) of Azerbaijan (fauna, biology, zoogeography and economic significance) Abstract of dissertation for candidate of biological sciences. Baku: 21 p. (in Russian).

**Babayev I.R.** (1990) Current status of the Swamphen in the Lenkaran lowland. *Ornitologiya*, **24:** 116-117 (in Russian).

**Babayev I.R.** (1991) Greater flamingo in the Lenkaran lowland. Ecology, protection, reproduction. *Proceedings of the scientific-practical conference*. Stavropol, pp. 32-36 (in Russian).

**Bogachev A.V.** (1951) Animal world of Azerbaijan. Section *Insecta*. pp. 271-406 (in Russian).

**Dashdamirov S.D.** (1988) A new species of pseudoscorpions of the genus *Acanthoreagris* (*Pseudoscorpiones, Neobisidae*) from Azerbaijan. *Zool. Journal*, **67(9):** 1414-1416 (in Russian).

**Dashdamirov S.D.** (1991) New finds of pseudoscorpions (*Arachnida, Pseudoscorpiones*) in the USSR. *Zool. Journal*, **70(9):** 64-69 (in Russian).

**Derzhavin A.N.** (1922) Sevruga (*Acipenser stellatus* Pallas): a biological essay. Baku. *Izvestiya Baku Ichthyol. Lab.*, **1(1):** 393 p. (in Russian).

**Derzhavin A.N.** (1947) Reproduction of sturgeon stocks. Baku: Publishing House of the Academy of Sciences of the Azerbaijan SSR. 248 p. (in Russian).

**Drapolyuk I.S.** (1982) *Dendrophilous Heteroptera* (*Heteroptera*) of the Greater Caucasus of Azerbaijan (with a review of the gadfly bugs of the genus *Tuponia* Reut. of the fauna of the USSR) *Abstract of a PhD thesis*. Baku: 23 p. (in Russian).

**Dubovchenko T.A.** (1968) Ectoparasites of bats of Azerbaijan. *Abstract of diss. candidate of biological sciences*, pp. 3-25. (in Russian).

**Dunin P.M.** (1984) Fauna and ecology of spiders (Aranei) of the Absheron peninsula (Azerbaijan SSR) Fauna and ecology of arachnids. *Interuniversity collection of scientific proceedings*. Perm, pp. 45-60. (in Russian).

**Dunin P.M.** (1992) Spiders of the *Dysderidae* family of the Caucasus fauna (*Arachnidae, Aranei, Haplogynae*). *Arthropoda Selecta*, 1, No. 3, pp. 36-76. (in Russian).

**Effendi R.M.** (1971) Higher Lepidoptera of Azerbaijan. A*bstract of Cand. Sci. (Biol.) Dissertation*. Baku: 25 p. (in Russian).

**Fataliyev G.G.** (1975) Nematodes of wild pigs of the Lesser Caucasus of Azerbaijan. *Mat. Scient.*

*asp. AN Azerb.USSR*. Baku: Elm, p. 62 (in Russian).

**Feyzullayev N.Z.** (1971) New parasitological concept. *Zool. Zh.* (Moscow), **50 (12):** 1865-1869 (in Russian).

**Gambarov K.M.** (1941) Catalogue of birds of Azerbaijan (*Passeridae*). Baku: AzFAN, 92 p. (in Russian).

**Hajiyev A.T.** (1983) Gamasoid mites of the Caucasus. Baku, Elm, 177 p. (in Russian).

**Hidayatov D.A.** (1982) Hemiptera groups of pentatomomorphs of Azerbaijan. Baku: Elm. 160 p. (in Russian).

**Huseynov E.F.** (2014) Natural prey of the crab spider *Xysticus marmoratus* (*Araneae:* T*homisidae*) on *Eryngium* plants. *The Journal of arachnology*, **42(1):** 130-132.

**Huseynov E.F., Marusik Y.M. & Koponen S.** (2005) Spiders (*Arachnida: Aranei*) of Azerbaijan. 5. Faunistic review of the funnel-web spiders (*Agelenidae*) with the description of new genus and species. *Arthropoda Selecta*, **14(2):** 153-177.

**Huseynova E.** (2013) Current state of jewel beetles (*Buprestidae*) in Azerbaijan. *International Caucasian Forestry Symposium (ICFS)*, Turkey: Artvin, p. 127-136. (in Russian).

**Huseynzade G.A.** (2001) Bee family *Halictidae (Hymenoptera, Apoidea*) of Azerbaijan. *Abstract of dissertation for candidate of biological sciences*. Baku: 23 p. (in Russian).

**Ibrahimov Sh.R.** (2012) Parasites and diseases of fish of the Caspian Sea: (ecological and geographical analysis, epizootological and epidemiological assessment) Baku: Elm, 395 p. (in Russian).

**Ibrahimova R.Sh.** (2021) Zoonotic helminths of domestic carnivores and their epizootological, epidemiological significance in Azerbaijan. Moscow: De'Libri, 192 p. (in Russian).

**Iskenderov T.M., Akhmedov S.B., Bunyatova S.N.** (2017) *Vipera lotievi* (*Pelias Lotievi*, *Serpentes, Viperidae*) - a new species for the fauna of Azerbaijan. *Zool. Journal*, **96 (1):** 121-124 (in Russian).

**Jafarov R.D.** (1949) Reptiles of the Azerbaijan SSR. Proceedings of the Natural History Museum of the Academy of Sciences of the Azerbaijan SSR. Baku, issue 3, 158 p. (in Russian).

**Jafarov Sh.M.** (1962) Blood-sucking midges (*Diptera, Heleidae*) of Transcaucasia (morphology, bioecology, geographic distribution, harmfulness, control measures and fauna of the genera *Culicoides, Leptoconops* and *Lasiohele*a). *Abstract of the dis. of doc. biol. sci.* L.: 52 p. (in Russian).

**Karimov T.** (2021) Distribution, biology and protection of scavenger birds (Aegypius monachus, *Gyps fulvus, Neophron percnopterus, Gypaetus barbatus*) in Azerbaijan. *Abstract of the dissertation for the degree of Doctor of Biological Sciences*. Baku: 47 p.

**Kasimov A.G.** (1972) Freshwater fauna of the Caucasus. Baku: Elm, 286 p. (in Russian).

**Kasimov A.G.** (2004) Ecology of plankton of the Caspian Sea. Baku: Adyloglu Publishing House, 545 p. (in Russian).

**Kerimova I.G.** (2019) *Neuroptera* of the Greater Caucasus of Azerbaijan. *Mountain Ecosystems and Their Components. VII All-Russian Conference with International Participation*, Nalchik: p. 127-128 (in Russian).

**Kerimova I.G., Krivokhatsky V.A.** (2018) Modern Composition of the Antlion Fauna (*Neuroptera: Myrmeleontidae*) of Azerbaijan. *Caucasian Entomological Bulletin*, **14 (1):** 55–66 (in Russian).

**Khanmammadov A.I.** (1971) Galliformes of Azerbaijan. Baku: Elm, 213 p. (in Azerbaijani)

**Kuliev Z.M.** (1989) Fishes of the Kirov Bay of the Caspian Sea. Baku: Elm, 184 p. (in Russian).

**Kuliyev Z.** (2018) Gazelle of Azerbaijan (*Artiodactyla: Gazella*) Goitered gazelle - *Gazella subgutturosa* Guld., 1780. Lambert Academic Publishing: 264 p. (in Russian).

**Kuliyeva H.F.** (2012) Ecological and physiological foundations for predicting the development of harmful insects, Lambert Academic Publishing: 164 p. (in Russian).

**Mamedov, Z.M.** (2004) Parasites of harmful lepidopteran fruit crops in Azerbaijan and ways of their use in biological protection. Baku: Elm, 236 p. (in Russian).

**Manafov A.A.** (2010) Mollusks of the genus *Melanopsis* (*Melanopsidae, Mesogastropoda* - «Prosobranchia») as intermediate hosts of trematodes in water bodies of Azerbaijan. *Bulletin of the Mordovian University*, Saransk: **No. 1:** 132-138 (in Russian).

**Mikailov T.K.** (1975) Parasites of fish in water bodies of Azerbaijan (systematics, dynamics, origin). Baku: Elm, 297 p. (in Russian).

**Mirzoyeva N. B.** (1988) Leaf beetles of Azerbaijan. Baku: Elm. 298 p. (in Russian).

**Musayev M.A., Veysov A.M.** (1965) *Coccidia* of rodents of the USSR. Baku: 154 p. (in Russian).

**Mustafayev G.T.** (1993) Ecological summary. Baku: 204 p. (in Azerbaijani)

**Mustafayev N.J.** (2024a) Fish Fauna of Inland Water Basins of Azerbaijan. ADPU-publishing house, 2024, 308 p. (in Russian).

**Mustafayev N.J.** (2024b) Ichthyofauna of Azerbaijan. ADPU-publishing house, 225 p. (in Azerbaijani)

**Mustafayeva G.A.** (2020) Scale insects (*Hemiptera: Diaspididae*) of Azerbaijan, their parasites and predators. Lambert: 126 p. (in Russian).

**Nagiyev G.M.** (1962) Fauna and ecology of blood-sucking mosquitoes of the Lankaran natural region of the Azerbaijan SSR. *Abstract of dissertation for candidate of biological sciences*. Baku: 16 p. (in Russian).

**Novruzov N.** (2023) Biodiversity and Distribution of Scorpions and Solifuges (Arachnida, Scorpiones, Solifugae) in Eastern Transcaucasia. Biology Bulletin 50 (9), p.2160-2171.

**Nuruyeva T.V., Zamani A., Snegovaya N.Y.** (2024) A survey of mygalomorph spiders (*Araneae: Atypidae, Nemesiidae*) of Azerbaijan, including the description of two new species. *Zoology in the Middle East*, p.1-8.

**Nuruyeva T.V., Huseynov E.F.** (2021) A new species of the spider genus *Harpactea* Bristowe, 1939 (*Araneae: Dysderidae*) from Azerbaijan. *Zoology in the Middle East*, p. 26-30.

**Oskyrko O., Sreelatha L.B., Silva-Rocha I. et al.** (2022) Molecular analysis of recently introduced populations of the Italian wall lizard (*Podarcis siculus*). *Acta Herpetologica*, **17(2):** 147–157.

**Patrikeev M.** (2004) The birds of Azerbaijan (Faunistica). Pensoft Pub., 380 p.

**Radde G.** (1884) Ornithological fauna of the Caucasus (Ornis Caucasica) Tbilisi, 451 p. (in Russian).

**Radde G.** (1899) Museum Caucasicum, Zoology. **Vol. 1:** Tbilisi, 521 p.

**Rakhmatulina I.K.** (2005) Bats of Azerbaijan (fauna, ecology, zoogeography). 480 p. (in Russian).

**Rasulova Z. K.** (1980) Springtails of the Eastern part of the Lesser Caucasus of Azerbaijan. *Zool. Zh*., **issue Ch (11):** 1463-1467 (in Russian).

**Rasulova Z.K.** (1982) New species of springtails of the genus *Pseudosinella* (*Collembola, Entomobryidae*) inhabiting the soils of Azerbaijan. *Entomol. Obozrenie*, **XI(1):** 663-674 (in Russian).

**Rzayeva L.M.** (1986) Chalcids (Hymenopotera, Chalcidoidea) of Eastern Transcaucasia and their economic importance. *Abstract of PhD thesis*. Baku: 35 p. (in Russian).

**Sadikhov I.A.** (1962) Helminth fauna of fur animals of Azerbaijan. Baku: Elm, 159 p. (in Russian).

**Samedov N.G.** (1954) Grain beetles and measures to combat them. Baku: 132 p. (in Russian).

**Samedov N.G.** (1963) Fauna and biology of beetles that harm agricultural crops in Azerbaijan. Baku: Publishing house of the Academy of Sciences of the Azerbaijan SSR, 382 p. (in Russian).

**Snegovaya N.Y.** (2021) check list of the crane flies (*Insecta, Diptera, Tipuloidea: Pediciidae, Limoniidae And Tipulidae*) of the Azerbaijan Republic. *Munis Entomology & Zoology*, **16 (2):** 1133-1155.

**Snegovaya N.Y.** (2023) New data on the dragonflies of the Republic of Azerbaijan – a progress study in 2022. *Journal of the International Dragonfly Fund*, **176:** 1-30.

**Snegovaya N.Y., Kerimova I.G.** (2022) A Check-List of the Orthoptera of the Republic of Azerbaijan. *Munis Entomology & Zoology*, **17 (1):** 545-572.

**Snegovaya N.Y., Matov A.Y.** (2024) Revised checklist of the owlet moths (*Lepidoptera: Erebidae, Nolidae, Euteliidae, Noctuidae*) of the fauna of Azerbaijan. *Munis Entomology & Zoology*, **19(1):** 197-254.

**Snegovaya N.Y., Petrov V.A.** (2019) A catalogue of butterflies (*Lepidoptera, Rhopalocera*) of Azerbaijan. *Acta Biologica Sibirica*, **5(3):** 62-117.

**Snegovaya N.Y., Petrov V.A.** (2021) A list of *Sphingidae* (*Lepidoptera*) of Azerbaijan. *Acta Biologica Sibirica*, **7:** 103–124.

**Snegovaya N.Y., Shigayev C.** (2022) A checklist of the ants (*Insecta, Formicidae*) of Azerbaijan

Republic. *Iranian Journal of Animal Biosystematics*, **17(2):** 179-207.

**Snegovaya N.Y., Shirinova L.** (2022) Checklist of Aquatic beetles (*Coleoptera: Adephaga, Polyphaga*) in Azerbaijan Republic. *Iranian Journal of Animal Biosystematics*, **18(1):** 35-64.

**Snegovaya N.Yu.** (2014) Survey of the genus *Phalangium* Linnaeus, 1758 (*Phalangiidae: Opiliones*) from the Caucasus with description of two new species. *Fragmenta faunistica*, **57(1):** 1–19.

**Snegovaya N.Yu.** (2010) Further studies on harvestmen of the genus Opilio Herbst, 1798 (*Arachnida: Opiliones: Phalangiidae*) from the Caucasus. *Caucasian Entomological Bulletin*, **6(1):** 3-18

**Sultanov E., Gauger K., Humbatova S. et al.** (2020) Azerbaijan. In book: European Breeding Bird Atlas 2: Distribution, Abundance and Change. / Keller, V., Herrando, S., Voříšek, P. et al. European Bird Census Council & Lynx Editions, Barcelona. 967 p.

**Talibov T.T.** (1999) Species of rare animals of the Nakhchivan Autonomous Republic and protection of their gene pool. Baku: Elm, 102 p. (in Russian).

**Talibov T.T.** (2021) Fauna of the Nakhchivan Autonomous Republic. Orekhovo-Zuyevo: GGTU. 350 p. (in Russian).

**Talibov T.T., Mammadov A.F.** (2016) Taxonomic spectrum of the vertebrate fauna of the Nakhchivan Autonomous Republic. Baku: Uchitel Publishing House, 68 p. (in Russian).

**Trofimov G.K.** (1971) Synanthropic flies of Azerbaijan: (Fauna, geogr. distribution, data on the ecology and epidemiological significance of individual species; control measures). *Abstract of PhD thesis, biol. sciences*. Baku: 49 p. (in Russian).

**Tuayev D.G.** (2000) Catalogue of birds of Azerbaijan. Baku: 228 p. (in Russian).

**Vaidova S.M.** (1978) Helminths of birds in Azerbaijan. Baku: Elm, 235 p.

**Yusubov E.B.** (1984) Scorpions (*Arachnidae, Scorpiones*) of Azerbaijan. *Abstract of Cand. Sci. (Biol.) Dissertation*. Baku: (in Russian).

**Zhang Z.Q.** (2013) Animal biodiversity: An update of classification and diversity in 2013. *Zootaxa*, **3703(1):** 5-11.

**ORCIDS:**
Ilham Alekperov: https://orcid.org/0000-0002-6647-5573
Natalya Snegovaya: https://orcid.org/0000-0001-6060-6491
Elyana Tahirova: https://orcid.org/0000-0001-9559-9527

*Journal of Life Sciences & Biomedicine, vol. 6(79), No 2, p. 46-51 (2024)*

# The impact of climate change on phytocenoses in the mountainous part of Talysh

**Elshad Gurbanov[1*], Sanubar Aslanova[2]**

[1]*Baku State University, 33 Academician Zahid Khalilov Str., AZ1148, Baku, Azerbaijan*
[2]*Azerbaijan State Pedagogical University, 68 Uzeyir Hajibeyli Str., AZ1000, Baku, Azerbaijan*

[*]***For correspondence:*** *elshad_g@rambler.ru*

Received: September 1, 2024; Received in revised form: November 7, 2024; Accepted: December 10, 2024

**This article examines the impact of climate change on phytocenoses (vegetation cover) in the mountainous part of Talish. As a result of research conducted during 2020-2024, endangered or rare plant species were identified in this area. The research focused on analyzing vegetation productivity, forage quality, and summer pasture capacity as one of the main indicators for assessing the impact of climate change on biodiversity. Widespread plant formations in Yardimli, Lerik, and Astara regions were studied on a methodological basis, and the impact of these changes on ecosystem stability was analyzed. The results show that climate change affects the structural and functional characteristics of phytocenoses, narrows the distribution area of some species, and creates conditions for the emergence of new species associations. The long-term ecological impacts of these changes and the need for conservation measures are discussed.**

***Keywords:*** *Meteorological station, precipitation, biodiversity, phytocenosis, radiation*

## INTRODUCTION

The mountainous part of Talysh is considered one of the most important natural regions of Azerbaijan with its unique ecosystem and rich biodiversity (Aslanova, 2023; Aliyev et al., 2008). The unique climate and natural conditions of this region create a favorable environment for the spread of various plant species and the formation of ecosystems. However, in recent years, global warming and climate change have not left the ecosystem of the Talysh Mountains untouched (Gadzhiev et al., 1979; Gurbanov & Aslanova, 2023). These changes have led to serious changes in the phytocenoses of the region, the decline of some plant species, and even their extinction.

The climatic characteristics of the mountainous part of Talysh are one of the main factors determining the ecology and natural landscape of the region. These climatic zones have a variety of conditions, such as subtropical conditions with mild winters and dry and hot summers, as well as drought and harsh mountain climates. The climatic indicators of the Astara, Yardimli and Lerik regions, as well as the sharply continental climate of the Diabar basin, form the different vegetation and ecosystem dynamics of these areas (Safarov, 1980, Shikhlinsky, 2009; Mammadov, 2004).

This study investigates the climatic characteristics of the Talysh Mountains and the impacts of recent changes on the region's biodiversity (Hajiyev, 2004; Gurbanov & Jabbarov, 2017). The aim is to understand the impacts of climate change on ecosystems, establish a scientific basis for the conservation of endangered species, and contribute to ecological stability.

## MATERIALS AND METHODS

The natural vegetation cover of the mountainous areas of Yardimli, Lerik and Astara regions, which we studied, was grazed, as well as ungrazed (protected) areas.



https://doi.org/10.59849/2710-4915.2024.2.46
Available online 31 December 2024

In the study region of the mountainous part, the productivity of the formations *Thymuseta – Stipetum – Festucosum*; Leguminous – wheat - grassy subalpine meadows; *Trifolieta – Thymusetum – F estucosum* and Different-grassy subalpine meadows of the formation class *Thymuseta – Vicaetum – Festucosum* was determined according to the fresh and dry mass consumed (Gurbanov & Aslanova, 2024). In this regard, these formation classes were reflected in the "Ecological-geobotanical map of the vegetation of the mountainous part of Lankaran" - its legend, as well as contours No. 3, 5 and 14.

The results of our multi-year studies on the formations of vegetation types in the mountainous part of the territory are shown in Tables 1-5.

The amount of digestible nutrients (protein, fat, cellulose) in the corresponding phytocenoses was calculated based on the biochemical composition of the main fodder plants (analytical laboratory analyses) (Table 5), nitrogen-free extractive substances (NFE), feed units per 100 kg of feed and assimilated protein.

In the mountainous part of the region, it should be noted that its characteristics play an important role as an ecological factor in the formation of the flora biodiversity and phytocenoses of the territory (Aslanova, 2024).

## RESULTS AND DISCUSSION

Information on the yield, quality of fodder (nutrition) and pasture capacity of formations that have important fodder importance in the mountainous part of Talish adapted to different climatic conditions is given below.

### 1. Productivity, feed quality and capacity of *Thymuseta – Stipetum – Festucosum* formation

The vegetation cover of the formation was recorded in the summer pasture (grazed) field No. 3 of Yardimli district in the mountain-meadow steppe soil, and the productivity was determined here. Depending on the terrain, soil and climate of the area, its productivity varies from year to year (Table 1). The average perennial air temperature in the region is usually 11.9ºC and the amount of precipitation reaches 645 mm.

As can be seen from table 1, the approximate coefficient of conversion of the wet mass of the grass to the air-dry edible mass and vice versa for the determination of productivity in *Thymuseta – Stipetum – Festucosum* phytocenosis fluctuated in the range of 2.3-2.6.

Thus, in the first year of the study (July 2020), the average annual productivity was 15.6 cwt/ha in wet and 6.5 cwt/ha in dry mass, including wheat-grassy - 3.2 cwt /ha (49.2%), leguminous-grassy 1.5 cwt/ha (23.1%) and different-grassy 1.8 cwt/ha (27.7%).

In the summer of 2022 (July 15-20), the productivity increased compared to the previous year, i.e. 18.9 cwt/ha according to the wet mass; including wheat-grassy 10.2 cwt/ha, leguminous-grassy 3.0 cwt/ha and 5.7 cwt/ha different-grassy as well as 8.2 cwt/ha (4.4 cwt/ha wheat-grassy, 1.3 cwt/ha leguminous-grassy and 2.5 cwt/ha different-grassy) were noted. In the summer of 2024, the productivity (due to the heavy rainfall in the region) increased in contrast to previous years. In this regard, the average annual indicator in that year was 24 c/ha in wet mass (wheat-grassy – 13.3 c/ha, leguminous-grassy 4.5 c/ha, different-grassy – 6.2 c/ha) and 9 in dry mass. 6 c/ha (wheat-grassy – 5.1 c/ha, leguminous-grassy 2.6 c/ha and different-grassy 1.9 c/ha) changed.

The research results show that the three-year average yield of *Thymuseta – Stipetum – Festucosum* formation was 15.6-24.0 c/ha (wet) and 6.5-9.6 c/ha dry mass (table 1).

According to biochemical analyses of phytocenoses (Table 4) belonging to subalpine-meadow and frigana formations of the region, hygroscopic moisture is 13.0%, protein in absolute dry matter is 9.0%, fat is 2.1%, cellulose is 31.0% and NFE – corresponds to 36.9% (Gurbanov, 2004). According to the obtained results, 44.7 units of feed and 4.9 assimilated proteins are obtained in 100 kg of feed according to the feed quality of the formation, including its nutritional value.

**Table 1.** The average annual yield of the *Thymuseta – Stipetum – Festucosum* formation formed in the Yaharyurd summer pasture area No 3 of Yardimli district

| Years and months | Botanical herb groups | Wet mass | | Dry edible mass | |
|---|---|---|---|---|---|
| | | cwt/ha | % | cwt/ha | % |
| **2020 (10-15.VII)** | Wheat-grassy | 7.7 | 49.3 | 3.2 | 49.2 |
| | Leguminous-grassy | 3.6 | 23.1 | 1.5 | 23.1 |
| | Different-grassy | 4.3 | 27.6 | 1.8 | 27.7 |
| | Average annual productivity | 15.6 | 100.0 | 6.5 | 100.0 |
| **2022 (15-20.VII)** | Wheat-grassy | 10.2 | 54.0 | 4.4 | 53.7 |
| | Leguminous-grassy | 3.0 | 15.9 | 1.3 | 15.8 |
| | Different-grassy | 5.7 | 30.1 | 2.5 | 30.5 |
| | Average annual productivity | 18.9 | 100.0 | 8.2 | 100.0 |
| **2024 (20-25.VII)** | Wheat-grassy | 13.3 | 55.5 | 5.1 | 53.1 |
| | Leguminous- grassy | 4.5 | 18.7 | 2.6 | 27.1 |
| | Different-grassy | 6.2 | 25.8 | 1.91.9 | 19.8 |
| | Average annual productivity | 24.0 | 100.0 | 9.6 | 100.0 |

**2. Productivity, feed quality and capacity of *Trifolieta – Thymusetum – Festucosum* formation**

The change of the multi-year average yield of this formation (in the territory of the Lerik district in grassy mountain-meadow lands) was found to be 9.4-12.4 cwt/ha during the years 2020-2022-2024 (in the summer season) (Table 2).

It can be seen from the table that the drying coefficient of phytomass in determining the productivity of the formation is equal to 2.3-2.8.

In the first year of the study (2020), the wet mass was 28.6 cwt/ha - wheat-grassy 11.4 cwt/ha (39.9%), leguminous-grassy 9.2 cwt/ha (32.2%), different-grassy 8.0 cwt/ha (27.9%); in dry mass 5.4 cwt/ha (43.5%), wheat-grassy 3.7 cwt/ha (29.9%), leguminous-grassy and 3.3 cwt/ha (26.6%) different -grassy.

So, in July of that year (according to the multi-year data of the meteorological station of the region), the average monthly air temperature rose to 30-37ºC and the average annual amount of precipitation was 640 mm.

In 2022, the average annual productivity of the formation based on dry edible mass is set at 9.4 cwt/ha; of which wheat-grassy 5.2 cwt/ha (55.3%), leguminous-grassy 2.8 cwt/ha (29.8%) and different-grassy 1.4 cwt/ha (14.9%) were recorded.

In the third year of study (July 20-25; 2024), it had a higher yield (10.8 cwt/ha) in the same phytocenosis (Table 2), including 4.9 cwt/ha (45.4%) wheat-grassy, 2.4 cwt/ha (22.2%) leguminous-grassy and 3.5 cwt/ha (32.4%) different-grassy.

As shown in Table 4, the biochemical composition of the formation - hygroscopic moisture 14.5%, ash 7.8%, crude protein 10.4%, crude fat - 2.7%, crude cellulose 22.4% and NFE 42.2%. At the same time, 55.3 feed units and 5.6 assimilated protein per 100 kg of dry feed were calculated in the feed quality of vegetation (Gurbanov & Aslanova, 2024).

**Table 2.** The average annual yield of the *Trifolieta – Thymusetum – Festucosum* formation, which is distributed in the moist mountain-meadow soils in the territory of the Lerik region.

| Years and months | Botanical herb groups | Wet mass | | Dry edible mass | |
|---|---|---|---|---|---|
| | | cwt/ha | % | cwt/ha | % |
| **2020 (10-15.VII)** | Wheat-grassy | 11.4 | 39.9 | 5.4 | 43.5 |
| | Leguminous-grassy | 9.2 | 32.2 | 3.7 | 29.9 |
| | Different-grassy | 8.0 | 27.9 | 3.3 | 26.6 |
| | Average annual productivity | 28.6 | 100.0 | 12.4 | 100.0 |
| **2022 (15-20.VII)** | Wheat-grassy | 12.5 | 55.4 | 5.2 | 55.3 |
| | Leguminous-grassy | 6.7 | 29.6 | 2.8 | 29.8 |
| | Different-grassy | 3.4 | 15.0 | 1.4 | 14.9 |
| | Average annual productivity | 22.6 | 100.0 | 9.4 | 100.0 |
| **2024 (20-25.VII)** | Wheat-grassy | 12.7 | 42.1 | 4.9 | 45.4 |
| | Leguminous-grassy | 7.7 | 25.5 | 2.4 | 22.2 |
| | Different-grassy | 9.8 | 32.4 | 3.5 | 32.4 |
| | Average annual productivity | 30.2 | 100.0 | 10.8 | 100.0 |

*Trifolieta – Thymusetum – Festucosum* is superior to other formations in terms of productivity and feed quality. This can be clearly seen from table number 2. In 2020, wheat-grassy 5.4 cwt/ha (43.5%), leguminous-grassy 3.7 cwt/ha (29.9%), different-grassy 3.3 cwt/ha (26.6% ); In 2022, wheat-grassy was different (0.2 cwt/ha) compared to the previous year, 5.2 cwt/ha (55.3%), leguminous-grassy 2.8 cwt/ha (29.8%) and different-grassy 1.4 cwt/ha (14.99%) was recorded; In 2024, compared to the previous two years, productivity (due to high rainfall) increased. Wheat-grassy (decreased compared to 2020 and 2022) 4.9 cwt/ha (45.4%), leguminous-grassy 2.4 cwt/ha (22.2%) and different-grassy 3.5 cwt/ha (32.4%).

*Trifolieta – Thymusetum – Festucosum* formation three-year average productivity (10.9 cwt/ha), feed unit (55.3 kg), as well as phytocenosis usage period (120 days) and acceptance of 1.3 feed units of daily feed rate of small horned animals it is possible to determine the capacity (1154 small horned cattle) in summer pasture "Gizyurdu" (No. 12) (on 296 ha) of conventional pasture area load (3.9).

In general, taking into account the average annual productivity of the corresponding formation, the capacity of fodder quality per hectare, this phytocenosis can be attributed to the group of good-quality pasture. First of all, effective use of vegetation and implementation of surface improvement measures is appropriate.

**3. Productivity, feed quality and capacity of *Thymuseta – Vicaetum – Festucosum* formation**

The vegetation cover of the formation was recorded in the summer (ungrazed) pasture field No. 8 "Turksoba" in the territory of the Astara region in the mountain-brown soils that emerged from under the forest. The average annual temperature of the air typical of the climate of this region is 10-140ºC, and the annual amount of precipitation reaches 1400-1600 mm.

The research shows that the vegetation of this formation belongs to the Leguminous-wheat-grassy subalpine meadows formation class. The productivity of the *Thymuseta – Vicaetum – Festucosum* formation of this formation class in the summer season of 2020-2022-2024 ranges from 19.5-29.6 cwt/ha in wet mass and 7.8-12.9 cwt/ha in dry mass (Table 3). According to calculations, the coefficient of conversion of wet mass to dry mass of productivity corresponds to 2.3-2.5.

As seen in Table 3, the productivity of the formation was 19.5 cwt/ha in the summer of 2020; wheat-grassy - 9.0 cwt/ha (46.1%), leguminous-grassy 6.8 cwt /ha (34.9%), different-grassy 3.7 cwt /ha (19.0%); in dry edible mass - wheat-grassy 3.6 cwt/ha (46.1%), leguminous-grassy 2.7 cwt /ha (34.7%) and different-grassy 1.5 cwt /ha (19.2% ).

In the summer of 2020 (July 20-25), the average annual productivity of the formation (wet mass was 25.5 cwt/ha and dry mass) partially increased, that is, it reached 10.2 cwt /ha, including wheat-grassy 6.1 cwt/ha (59.8%), leguminous-grassy 2.5 cwt /ha (24.5%) and different-grassy 1.6 cwt /ha (15.7%).

On June 25-30, 2024, the productivity of phytocenosis increased compared to previous years due to favorable climatic conditions and rich soil fertility (humus). According to the productivity indicators of this year, 29.6 cwt /ha was found in the age group, of which wheat-grass 16.6 cwt /ha (56.1%), leguminous-grass 7.3 cwt /ha (24.7%) and distinct-grassy 5.7 cwt/ha (19.2%); 12.9 cwt/ha was determined in dry mass, including wheat-grassy 6.7 cwt /ha (51.9%), leguminous-grassy 3.8 cwt /ha (29.5%) and 2.4 cwt /ha (19.6%) different-organized grassy.

In the biochemical composition of the vegetation of the Thymuseta-Vicaetum-Festucosum formation, hygroscopic moisture - 14.7%, ash 7.0%, crude protein 11.1%, crude fat 2.8%, crude cellulose 23.5% were determined and based on these indicators 45.8 feed units and 4.6 assimilated protein were calculated per 100 kg (dry) feed (Table 4).

As can be seen from Table 3, the average annual productivity of the blueberry-grass-limp formation is variable for botanical groups. So, in the summer of 2020 (dry mass) - 7.8 cwt /ha- wheat-grassy 3.6 cwt/ha (46.1%), leguminous-grassy 2.7 cwt/ha (34.7%), different-grassy 1.5 cwt /ha (19.2%); In 2022 (summer) 10.2 cwt /ha – wheat-grassy 6.1 cwt /ha (59.8%), leguminous-grassy 2.5 cwt /ha (24.5%), different-grassy 1.6 cwt/ha (15.7%) and in 2024, 12.9 cwt /ha– wheat-

grassy 6.7 cwt/ha (51.9%), leguminous-grassy 3.8 cwt /ha (29.5%), and different-grassy fluctuated at the limit of 2.4 cwt /ha (18.6%).

**Table 3.** The average annual productivity of the *Thymuseta – Vicaetum – Festucosum* formation spread in the summer pasture area No. 8 "Turkesoba" of the Astara region

| Years and months | Botanical herb groups | Wet mass | | Dry edible mass | |
|---|---|---|---|---|---|
| | | cwt/ha | % | cwt/ha | % |
| **2020 (10-20.VII)** | Wheat-grassy | 9.0 | 46.1 | 3.6 | 46.1 |
| | leguminous-grassy | 6.8 | 34.9 | 2.7 | 34.7 |
| | different-grassy | 3.7 | 19.0 | 1.5 | 19.2 |
| | Average annual productivity | 19.5 | 100.0 | 7.8 | 100.0 |
| **2022 (20-25.VII)** | Wheat-grassy | 15.2 | 59.6 | 6.1 | 59.8 |
| | leguminous-grassy | 6.3 | 24.7 | 2.5 | 24.5 |
| | different-grassy | 4.0 | 15.7 | 1.6 | 15.7 |
| | Average annual productivity | 25.5 | 100.0 | 10.2 | 100.0 |
| **2024 (25-30.VII)** | Wheat-grassy | 16.6 | 56.1 | 6.7 | 51.9 |
| | leguminous-grassy | 7.3 | 24.7 | 3.8 | 29.5 |
| | different-grassy | 5.7 | 19.2 | 2.4 | 18.6 |
| | Average annual productivity | 29.6 | 100.0 | 12.9 | 100.0 |

**Table 4.** Biochemical compositions of the formations belonging to the subalpine meadow and frigana phytocenoses of the mountainous part of Talish

| № | Formations | Hygroscopic moisture, % | In absolute dry matter, in % | | | | | In 100 kg | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Ash | Crude protein | Crude oil | Crude cellulose | NFE | Feed unit | Absorbed protein |
| **1.** | *Thymuseta – Stipetum – Festucosum* | 13.0 | 8.0 | 9.0 | 2.1 | 31.0 | 36.9 | 44.7 | 4.9 |
| **2.** | *Trifolieta – Thymusetum – Festucosum* | 14.5 | 7.8 | 10.4 | 2.7 | 22.4 | 42.2 | 55.3 | 5.6 |
| **3.** | *Thymuseta – Vicaetum – Festucosum* | 14.7 | 7.0 | 11.1 | 2.8 | 23.5 | 40.9 | 45.8 | 4.6 |

**Table 5.** Duration of use of phytocenoses, average productivity, feed quality and pasture capacity in some plant formations in the summer season of 2020-2022-2024

| № | Formations | Duration (in days) | Average yield (in edible dry mass), kg | In 100 kg | | Number of grazing cattle per hectare (load) | area (ha) | Pasture capacity |
|---|---|---|---|---|---|---|---|---|
| | | | | Feed unit | Absorbed protein | | | |
| **1.** | *Thymuseta – Stipetum – Festucosum* | 120 | 8.1 | 44.7 | 4.9 | 2.3 | 333 | 766 |
| **2.** | *Trifolieta – Thymusetum – Festucosum* | 120 | 10.9 | 55.3 | 5,6 | 3.9 | 296 | 1154 |
| **3.** | *Thymuseta – Vicaetum – Festucosum* | 120 | 10.1 | 45.8 | 4.6 | 3.0 | 90 | 270 |

In our studies, the pasture capacity was determined mainly by taking into account the period of use of *Thymuseta – Stipetum – Festucosum* phytocenosis, productivity, feed unit and daily feed rate of cattle (Table 5). As can be seen from the table, the average productivity of the formation is 8.1 cwt/ha, the feed unit is 44.7 kg per 100 kg of feed, and the daily feed rate is 1.3 feed units and the pasture capacity was found to be 766 animals.

The average annual yield (in 2020-2022-2024) of the *Trifolieta – Thymusetum – Festucosum* formation is 10.9 cwt/ha, feed unit (in 100 kg of dry feed) - 55.3 kg, vegetation use or grazing period - 120 days. Based on the daily feed rate of small horned animals - 1.3 feed units, it was found that 1154 cattle were grazing on 296 ha.

As can be seen in Table 5, the three-year average productivity of the *Thymuseta – Vicaetum*

– *Festucosum* formation (10.1 cwt/ha), feed unit per 100 kg of dry fodder (45.8 kg), duration of phytocenosis (120 days) and daily consumption of small horned animals taking into account the fodder norm (1.3 fodder units), 3.0 cattle per hectare, and the pasture capacity (270 small horned cattle can be grazed) was determined in the total area (90 ha).

Thus, based on the characteristics of the climatic conditions in the mountainous part of Talysh, we conclude that due to the decrease in precipitation and the increase in temperature, the productivity of summer pastures decreases, the degradation of phytodiversity and the desertification of soil-vegetation cover continue.

Therefore, it is appropriate to implement measures to protect, efficiently (correctly) use and improve phytocenoses in natural summer pastures of the region. Therefore, recommendations on comprehensive measures for protection, efficient use and improvement of flora biodiversity in the ecosystem of the territory were prepared on a scientific basis.

In the mountainous part of the region, it is proposed to create a buffer strip on the border of summer pastures and forests of the Yardimli region in order to protect the flora of the area, as well as endemic, rare and endangered plants, and to use the recommendations made by the State Ministry of Ecology and Natural Resources of the Republic of Azerbaijan for the protection of phytocenoses. The implementation of these recommendations will allow the protection of the area's biodiversity and vegetation.

## REFERENCES

**Aslanova S.** (2023) Phytocoenological characteristics and ımportance of vegetation on the territory of Lerik district (Azerbaijan). *Bulletin of Science and Practice*, **9(9):** 69-76; doi:10.33619/2414-2948/94/07 (in Russian).

**Aslanova S.** (2024) Subalpine meadow vegetation of Talish highlands of Azerbaijan. *Bulletin of Science and Practice*, **10(2):** 38-46; doi: 10.33619/2414-2948/99/04.

**Aliyev C.A., Akparov Z.I., Mammadov A.T.** (2008) Biological diversity. Baku: Elm, 232 p.

**Ayyubov A.C.** (2009) Main climate types. Ecological atlas of the Republic of Azerbaijan. Baku: DTXK, MEA; Baku: Cartography Factory, p. 21.

**Gurbanov E.M.** (2004) Flora and vegetation of Atropatena province (within Azerbaijan Republic). *Autoreferat of dissertation for the degree of doctor of biological sciences*. Baku, Azerbaijan. 234 p.

**Gurbanov E., Aslanova S.** (2023) Phytocenoses found in grassy mountain-meadow soils in the subalpine zone of Talish. All Sciences Proceedings, **1(2):** 81-84; doi: 10.59287/as-proceedings.129

**Gurbanov E., Aslanova S.** (2024) Average annual productıvıty of the *Thymuseta-Vıcaetum-Festucosum* formatıon, dıstrıbuted ın summer pasture fıeld No. 8 "Turkesoba" (Azerbaıjan). *Norwegian Journal of Development of the International Science*, **126:** 9-12.

**Hajiyev V.C.** (2004) The ecosystem of highland vegetation of Azerbaijan. Baku: 139 p.

**Gurbanov E.M., Jabbarov M.T.** (2017) Geobotany. Baku: Baku State University publishing house. p. 320

**Mammadov G.S.** (1998) Ecological assessment of Azerbaijani soils. Baku: Elm, 282 p.

**Mammadov G.S.** (2004) Ecoethical problems of Azerbaijan: Scientific, legal, moral aspects. Baku: Elm, 377 p.

**Mammadova S.Z., Shabanov C.A., Guliyev M.B.** (2005) Ecological monitoring of Lankaran river basin lands. Baku: Elm, 166 p.

**Gadzhiev V.D., Kulieva Kh.G., Vagabov Z.V.** (1979) Flora and vegetation of high altitude Talysh. Baku: Elm, 150 p.

**Safarov I.S.** (1980) Forest vegetation of high-mountain districts of Talysha and its phytocenotic features. Baku: 325 p.

**Shikhlinsky E.M.** (2009) Climate map of Azerbaijan. Scale 1:500000. Ecological Atlas. Baku: p. 20-21.

**ORCIDS:**
Elshad Gurbanov: https://orcid.org/0000-0003-4627-3760
Sanubar Aslanova: https://orcid.org/0000-0001-8371-1454

*Journal of Life Sciences & Biomedicine, vol. 6(79), No 2, p. 52-58 (2024)*

# Global climate variability and critical problems of biodiversity of Nakhchivan Autonomous Republic

**Tariyel Talibov**[1,2]

[1]*Institute of Bioresources (Nakhchivan), Ministry of Science and Education of the Republic of Azerbaijan, 32 M.F.Axundov Str., AZ7000, Nakhchivan, Azerbaijan*
[2]*Nakhchivan State University, University Campus, AZ7012, Nakhchivan, Azerbaijan*

***For correspondence*:** *t_talibov@mail.ru*

Received: October 1, 2024; Received in revised form: November 12, 2024; Accepted: December 15, 2024

**The article describes the critical problems occurring in the biodiversity of the Nakhchivan Autonomous Republic due to global climate change. Specially protected natural areas created in the autonomous republic to eliminate essential problems in biodiversity and their importance are noted, the taxonomic composition and rare species of fauna and flora biodiversity are shown. In the fauna biodiversity, the following species are included: from reptiles, *Rhynchocalamus melanocephalus* Jan and from birds, *Chettusia gregaria* Pall have the status of *Critically Endangered* (CR). The species, such as Striped Hyena, Marbled polecat, and Manul are no longer found in the area. 27 species of flora biodiversity have Critically Endangered (CR) status, and their seed material is intended to be collected and stored in a genebank.**

***Keywords:*** *Global climate change, fauna, flora, biodiversity, category, rare species*

## INTRODUCTION

Recently, global climate changes on Earth continue to cause serious consequences in nature. Factors such as the shrinking of distribution areas or biotopes, changes in the quality of habitat, degradation, and reduction of food objects indicate that the survival of species is at a critical level. Despite the expansion of special protection networks as a preventive measure by the state and the creation of an optimal environment for the protection of species, global climate change can still create critical problems for species in nature. First, the plant world, which is the beginning of the food chain, gets into a critical situation, and then, herbivores and, successively, carnivores suffer.

## MATERIALS AND METHODS

The fauna and flora biodiversity of the Nakhchivan Autonomous Republic served as the research material. During the research, various types of binoculars, such as a Swarovski telescope, photo traps, and GPS were used to determine the coordinates for species identification.

## RESULTS AND DISCUSSION

One of the important factors in creating a favorable ecological environment in the territory of the Nakhchivan Autonomous Republic is the protection and restoration of the uniqueness of the natural environment, plant and animal resources, the basis of which is specially protected natural areas. In 1989, when the National Leader Heydar Aliyev came to power, the Ordubad State Nature Reserve with an area of 40,000 ha was established in the Nakhchivan Autonomous Republic. Then, on June 16, 2003, the President of the Republic of Azerbaijan Heydar Aliyev signed an order on the establishment of the Shahbuz State Nature Reserve (3,139 ha) and the Ordubad National Park named after Academician Hasan Aliyev (12,131 ha) with the aim of protecting the



https://doi.org/10.59849/2710-4915.2024.2.52
Available online 31 December 2024

environment, its efficient use, preserving rare and endangered plant and animal species, and developing the network of specially protected natural areas of the Republic. At that time, 27,869 ha of area was planned for the Ordubad reserve. On September 23, 2005, the Arazboyu State Nature Reserve with an area of 9,118 ha and on June 22, 2009, the Arpachay State Nature Reserve with an area of 68,911.18 ha were established. The establishment of the Zangezur National Park (ZNP) named after Academician Hasan Aliyev with an area of 42,787 ha by the decree of the President of the country dated November 25, 2009, created conditions for the development of ecotourism along with nature conservation. Specially protected natural areas in the autonomous republic have increased by more than 3.7 times compared to 1995, and currently, 148,695.18 ha of the autonomous republic, with an area of 550,275 ha, or in other words, up to 27.02%, are specially protected natural areas, which is an important ecological factor and even higher than in developed countries. It should be noted that in developed countries with a friendly attitude towards nature, this indicator is approximately 10-15% (Talibov, 1999; Talibov, 2003; Talibov, 2021).

In the field of nature protection, for the first time, in order to register and provide special protection to rare and endangered plant and animal species, according to the decree of the Chairman of the Supreme Assembly dated August 15, 2006, we prepared two-volume Red Books on the flora and fauna of the Nakhchivan Autonomous Republic, and at the same time, we published more than 30 books and monographs on the fauna and flora of the area. In general, based on our research on flora and fauna, 408 species of vertebrates belonging to 5 classes, 33 orders, 101 families, and 271 genera were recorded in the territory of the Nakhchivan Autonomous Republic (Table 1). At the same time, 3021 species of higher spore, gymnosperm and angiosperm plants belonging to 104 orders, 160 families and 910 genera were discovered in the area (Table 2).

Reflecting more than half of the biodiversity of the Republic of Azerbaijan, the biodiversity of the Nakhchivan Autonomous Republic, according to our research and observations, has been significantly changing every year for the last 20-25 years due to climatic factors and especially the radiation background, along with other factors, putting many of the existing species in a critical situation and at risk of extinction. The 3rd edition of the Red Book, which was published in 2023 with the care and support of the state head, reflects 241 rare and endangered fauna species (152 vertebrates, 89 invertebrates) and 460 flora species (423 plants: 383 higher, 15 higher spore plants, 6 mosses, 14 lichens, 5 algae; 37 mushrooms) (Taxonomic spectrum of the fauna of Azerbaijan (Vertebrates), 2020; Talibov et al., 2018; Talibov, Mammadov, 2016; Talibov et al., 2021).

**Table 1.** Species composition of vertebrates of the Nakhchivan AR

| Classes | Order | | Family | | Genus | | Species | |
|---|---|---|---|---|---|---|---|---|
| | Azerbaijan | Nakhchivan AR | Azerbaijan | Nakhchivan AR | Azerbaijan | Nakhchivan AR | Azerbaijan | Nakhchivan AR |
| **Cyclostomata** | 1 | - | 1 | - | 1 | - | 1 | - |
| **Fish** | 12 | 6 | 17 | 9 | 53 | 28 | 107 | 33 |
| **Amphibians** | 2 | 1 | 5 | 4 | 7 | 5 | 9 | 6 |
| **Reptiles** | 2 | 2 | 13 | 13 | 37 | 32 | 63 | 39 |
| **Birds** | 19 | 18 | 64 | 54 | 210 | 160 | 409 | 260 |
| **Mammals** | 7 | 6 | 26 | 21 | 61 | 46 | 115 | 70 |
| **Total** | 43 | 33 | 126 | 101 | 369 | 271 | 704 | 408 |

**Table 2.** Higher spore, gymnosperm and angiosperm plants of the Nakhchivan AR

| No | Phylum | Classes | Order | Family | Genus | Species |
|---|---|---|---|---|---|---|
| **1.** | ***Bryophyta*** | 2 | 15 | 37 | 79 | 127 |
| **2.** | ***Equisetophyta*** | 1 | 1 | 1 | 1 | 7 |
| **3.** | ***Polypodiophyta*** | 1 | 2 | 6 | 11 | 15 |
| **4.** | ***Pinophyta*** | 1 | 2 | 4 | 14 | 22 |
| **5.** | ***Gnetophyta*** | 1 | 1 | 1 | 1 | 3 |
| **6.** | ***Magnoliophyta:*** | | | | | |
| | ***- Monocotyledoneae*** | 1 | 20 | 24 | 159 | 578 |
| | ***- Dicotyledoneae*** | 1 | 63 | 87 | 645 | 2269 |
| | **Total:** | 8 | 104 | 160 | 910 | 3021 |

The Red Books play an important role as a guiding document for the protection of the biodiversity of the Republic, the identification of endangered species of fauna and flora and the

further strengthening of protection measures. The decrease, rather than the increase, of the numbers in the Red Books is considered a victory of humanity over nature. Therefore, these books are prepared and published for this very purpose. The Red Books are the red borders of the path of living nature towards extinction and a call not to cross the red borders between man and nature. If we consider the dynamics of the numbers of species included in all volumes of the Red Books from the territory of the Nakhchivan Autonomous Republic, then we will see that there are indeed critical problems in the problem of protecting our nature. The following data for vertebrates confirms this idea more fully (Table 3).

Of the 704 species found in the Republic of Azerbaijan, 408 were discovered in the territory of the Nakhchivan Autonomous Republic. If we examine them in order, the picture is as follows:

One species of Cyclostomata is listed in the Red Book and is not found in the territory of the Nakhchivan Autonomous Republic.

Out of 107 species of fish, 33 are distributed in the territory of the Nakhchivan Autonomous Republic, the low number of these species can be attributed to the absence of large mammals in the area and due to critical climate change in the last decade, almost none of the rivers can normally connect with the Araz River. Therefore, it is likely that serious reductions in the number of species of fish fauna will be observed in the future (Red Book of the Republic of Azerbaijan. Second edition. Fauna, 2013; Red Book of the Republic of Azerbaijan Third edition. Fauna, 2023).

**Table 3.** Number dynamics of vertebrates included in the Red Books of the Nakhchivan Autonomous Republic

| Classes | Total species number | | Azerbaijan | | | Nakhchivan | | |
|---|---|---|---|---|---|---|---|---|
| | Azerb. | Nakhch. | 1989 | 2013 | 2023 | 2006 | 2013 | 2023 |
| **Cyclostomata** | 1 | - | - | 1 | 1 | - | - | - |
| **Fish** | 107 | 33 | 4 | 9 | 11 | 1 | 1 | 2 |
| **Amphibians** | 9 | 6 | 3 | 4 | 6 | 1 | 1 | 1 |
| **Reptiles** | 63 | 39 | 8 | 14 | 18 | 10 | 12 | 9 |
| **Birds** | 409 | 260 | 36 | 71 | 88 | 39 | 64 | 47 |
| **Mammals** | 115 | 70 | 14 | 41 | 40 | 20 | 26 | 22 |
| **Total** | 704 | 408 | 65 | 140 | 164 | 71 | 104 | 81 |

Amphibians are represented in Azerbaijan by a small number - 9 species, and 6 species were discovered in the autonomous republic. Of these species, 3 were included in the Red Book in the Republic of Azerbaijan in 1989, 4 in 2013, and 6 in 2023, of which, in the territory of the Nakhchivan Autonomous Republic, only Syrian spadefoot was included in the Red Book.

The reptile class is represented by 63 species, of which 39 species were found in the territory of the Nakhchivan Autonomous Republic. In 1989 – 8, in 2013 – 14 and in 2023 – 18 species were included in the Red Book for the Republic of Azerbaijan, of which 10, 12 and 9 species were included in the Red Book in the territory of the Nakhchivan Autonomous Republic, respectively. The decrease in data in 2023 is only due to the fact that some of these species, although they are present in the territory, were not marked on the maps due to a technical error.

The class of birds is represented by 408 species, of which 260 species were found in the territory of the Nakhchivan Autonomous Republic. In the Republic of Azerbaijan, 36 species were included in the Red Book in 1989, 71 in 2013, and 88 in 2023, of which 39, 64, and 47 species were included in the Red Book in the territory of the Nakhchivan Autonomous Republic, respectively. The decrease in data in 2023 is only due to the fact that some of these species were not recorded in the territory due to a technical error.

The class of mammals is represented by 115 species, of which 70 species were discovered in the territory of the Nakhchivan Autonomous Republic. In 1989 - 14, in 2013 - 41 and in 2023 - 40 species were included in the Red Book of the Republic of Azerbaijan, of which in the territory of the Nakhchivan Autonomous Republic, respectively, 20, 26 and 22 species were included in the Red Book. The decrease in the information in 2023 is only due to the fact that some of these species were not recorded in the territory due to a technical error. In the monograph we present, you can also see the works of H.S.Rasulzade (Talibov, Rasulzade, 2021). Rare waterfowl of the Nakhchivan Autonomous Republic), who also defended his dissertation on ornithology. Most of the newly discovered species are confirmed by original photographs.

Thus, out of 164 rare and endangered vertebrate species listed in the latest edition of the Red Book of the Republic of Azerbaijan, 81 species are distributed in the territory of the

Nakhchivan Autonomous Republic. Thus, approximately half of the rare species are also found in the territory of the Nakhchivan Autonomous Republic, and the distribution of some species is limited only to the territory of the Nakhchivan Autonomous Republic. If a species has not been found in nature for several years and has probably remained in natural landscapes inaccessible to humans, and is also under threat of extinction in the future, then the species is included in the CR status. In the fauna biodiversity, from the reptiles, *Rhynchocalamus melanocephalus* Jan, and from the birds, *Chettusia gregaria* Pall. have been classified as CR, but the vast majority of rare species are Endangered - EN and Vulnerable - VU. With the research and observations we conducted, as well as the camera traps we set, none of the mammal species *Hyaena hyaena* L.; *Vormela peregusna* Guldenstaedti, and *Otocolobus manul* Pall. have been observed in the area.

Global climate changes occurring on Earth have had a more serious impact on the plant world since plants, unlike animals, are deprived of the ability to move and therefore, suffer more damage during sharp climate changes, remaining in the place where they grow. Studies show that the number of plant species listed in the Red Book has also increased over the years. In the last volume of the Red Book, the number of such species that are critically endangered in the territory of the Nakhchivan Autonomous Republic alone was 27. When it is assumed that the populations of the studied species may be severely damaged during floristic studies, it can be attributed to the Critically Endangered category. Thus, out of 3021 higher spore, gymnosperm and angiosperm plant species of the Nakhchivan Autonomous Republic flora, 27 species whose current state in nature is at a critical level or whose descendants are presumed to be extinct belong to the CR status (Red Book of the Republic of Azerbaijan. Second edition, 2013; Red Book of the Republic of Azerbaijan. Third edition, 2023; Talibov, 2009).

1. *Epipactis veratrifolia* Boiss.et Hohen. – It was considered to have VU C2 status in the Red Book of the Nakhchivan Autonomous Republic (NAR), but due to the drastic changes in nature over the past 13 years, the species' survival opportunities have also decreased. Therefore, in the III edition of the Red Book of the Republic of Azerbaijan, it has CR B1ab(ii) status.
2. *Allium tripedale* Trautv. *(Nectaroscordum tripedale* (Trautv.) Grossh.) – This species has been given the status CR B2ab(ii) in the publications of the NaxQK and AzQK. In the area, it is found only in small groups in the areas at the foot of Demirlidagh in the Julfa region and Soyugdagh in the Ordubad region. We only discovered a pure formation of this species at the foot of Gaplan Rock in the Nus-Nus village of the Ordubad region. In that area, we discovered and described a white-flowered variation of the species - *Allium tripedale* Trautv. var. alba Talibov. It is cultivated in the Botanical Garden of the Institute of Bioresources. It was introduced by us to the Institute of Dendrology (Figure 1).
3. *Triticum boeoticum* Boiss. This species has not been discovered for a long time, despite serious searches, in the area of the Garagush mountain of the Deralayaz range. According to the literature, the NaxQK is currently maintained with the status of CR A1c; B2ab(I,II)+C2a(i), and the AzQK is maintained with the status of CR A1c+C2a(i).
4. *Triticum timopheevii* (Zhuk.) Zhuk. – Timofeyev wheat (*T.araraticum* Jakubz.). NaxQK CR A1c;B2ab(i,ii)+C2a(i), AzQK CR A1c+C2a(i). This variety has not been found in the wild either. It was preserved based on literature materials.
5. *Aristolochia bottae* Jaub. & Spach. It is a monotypic representative of the genus, found in a narrow areal, NaxQK CR B2a. It is found singly in zones adjacent to cultivated fields. Unfortunately, it is found only in a small area near the village of Nursu in the Shahbuuz region and has not been found in other zones. Attempts are being made to cultivate it using seeds collected in the Botanical Garden of the Institute of Bioresources (Figure 2).
6. *Dianthus libanotis* Labill. – Status-AzQK CRB2b(iii). It grows in the Ashabi-Kahf and Nahajir mountain areas in the Nakhchivan Autonomous Republic. It will be protected within the ZNP area.
7. *Quercus infectoria* subsp. *veneris* (A.Kern.)

Meikle (*Q. araxina* (Taurtv.) Grossh.) - Status-AzQK CR A1ab;B1bc(iii,iv). According to literature, it is found in the Babek and Ordubad regions, but currently, only in the area where the Kilit village of Ordubad region joins the Araz River, there is a small grove.

8. *Iberidella trinervia* Boiss. (*Aethionema trinervium* (DC.) Boiss.) – Status-AzQK CR B2a. Found only in the territory of Nakhchivan Autonomous Republic, the QK has been newly added.
9. *Physoptychis caspica* (Habi.) V.Boczantzeva – It is a unique-looking, specific plant, and is included in the NaxQK and AzQK CR B2ac(i);C2a(i) status. It is distributed in small groups on the high peaks of the Ordubad Mountain area of the Zangezur Range.
10. *Sorbus roopiana* Bordz. (*Hedlundia roopiana* (Bordz.) Sennikov et Kurtto) - Status-Az.QK CR B2b(ii,iii). It is found in the Bichenak and Derebogaz areas of the Shahbuz district. It is planned to collect seed material of this species and propagate it in the Botanical Garden.
11. *Colutea komarovii* Takht. It is an ornamental shrub. This species has been given the status CR B1ac(ii,iv);C2a(i) in the publications of the NaxGK and AzGK. It grows in small groups on the rocks in the area of Kotam village, Ordubad district of the Zangezur range. So far, it has only been found in small groups in the area called Sari Gaya of Kotam village and the plane grove of Kotamchay. It was introduced by us to the Institute of Dendrology.
12. *Astragalus caraganae* Fisch. & C.A.Mey. (*A.nachitschevanicus* Rzazade) – Status-NaxQK CRB1ac(i), AzQK CR B1ab(i,ii,iii)c(i)+2ab(i,ii,iii)c(i). It is a species with a decorative appearance and is of importance as a food. Its typical distribution area is around the village of Turkesh in the Shahbuz region.
13. *Astragalus montis-aquilis* Grossh. – Status-AzQK CR B2c(ii,iv). It is found singly around the village of Chalkhangala in Kangarli district and in the area of the Garagush Mount. It will be protected within the ZNP area.
14. *Astragalus ordubadensis* Grossh. – It grows singly in the Ordubad region on the territories of Soyug Dag and Ajnovur Dag. Status-AzQK CRB2a.
15. *Astragalus paradoxus* Bunge – Status-NaxQK CR B1ac(i), AzQK CR A2c+3c; B1ac(i)+2ab(i,ii,iii). It grows in small groups around the village of Nehram in the Babek region, the Alinjachay Valley in the Julfa region, and the village of Chennab in the Ordubad region. It is a beautiful ornamental plant and is protected within the ZNP area.
16. *Astragalus pinetorum* Boiss. (*A.badamliensis* Chalilov) – *Astragalus badamliensis* Chalilov. Status-NaxQK CRB1ac(ii,iv)+C2a(i) və AzQK CR A2c+3c;B1ac(i)+2ab(i,ii,iii). It is spread in small groups around the villages of Turkesh, Badamli and Kukudagg in the Shahbuz region.
17. *Oxytropis savellanica* Bunge ex Boiss. – Status-AzQK CR B2a. It grows in small groups in the villages of Tivi and Bist, in the Soyuzdag area of the Zangezur range in the Ordubad district. It will be protectd within the ZNP area.
18. *Trifolium bordsilovskyi* Grossh. – Status-AzQK CR B2a. It grows in small groups in the Batabat area of the Shahbuz district.
19. *Apium nodiflorum* (L.) Lag. (*Helosciadium nodiflorum* (L.) W.D.J.Koch) – Status-AzQK CR B2a. Found singly in the low hills around the villages of Hamzali and Akhura in the Sharur region. It will be protected within the ZNP area.
20. *Ferula oopoda* (Boiss. & Buhse) Boiss. – Status-NaxQK CR C2a(ii), AzQK CR B2ab(ii,iii);C2a(ii). It is distributed singly in a limited area, in a small group around Duzdag in the Babek district. Seed material will be collected and cultivated in the Botanical Garden. It is protected within the ZNP area.
21. *Jurinea spectabilis* Fisch. & C.A.Mey. – Status-NaxQK və AzQK CR A2cd. It grows singly under rocks in the Ordubad region, around Soyugdag. It is decorative.
22. *Podospermum grossheimii* (Lipsch. & Vassilcz.)Kuth. (*Scorzonera grossheimii* Lipsch. et Vassilcz.) – Status-NaxQK CRB1ac(i), AzQK CR B2ab(ii,iii,iv,v). It is found on rocks in the Kapicig and Soyugdagh areas of the Zangezur range in the Ordubad district. It is protected within the ZNP area.
23. *Nonea cyanocalyx* M.Pop. ex V.N.Karimov – Status-AzQK CR B2b(v). It grows in small

groups around Lake Batabat in the Shahbuz region and in the Bichenak Pass. It will be protected within the ZNP area.

24. *Onosma gracilis* Trautv. – Status-AzQK CR B1b(i,iii)+ 2b(ii,iii,v). It is found in the villages of Bilev and Tivi in the Ordubad district. It will be protected within the ZNP area.
25. *Onosma zangezura* T.N.Pop. – Status-AzQK CR B2b(ii,iii). It is found in the villages of Leketagh and Bayahmed in the Julfa district.
26. *Veronica multifida* L. (*V.arceuthobia* Woronow) – Status-AzQK CR B2a. It will be protected within the ZNP area.
27. *Ajuga chamaecistus* Ging. ex Benth. – Status-AzQK CR B2a. It will be protected within the ZNP area.

Monitoring of the listed species has already begun with the participation of employees of the Ministry of Ecology and Natural Resources of the Nakhchivan Autonomous Republic. Efforts will be made to include the collected materials and research results in the second edition of the Red Book of the Nakhchivan Autonomous Republic. In addition, along with the introduction of rare species of the autonomous republic in the Botanical Garden, it was decided to collect their seed materials in nature and store them in gene banks.

At this time, the most attention will be paid to *Critically endangered* – species whose condition in nature is at a critical level or is likely to be extinct, *Endangered* – species whose number dynamics in nature continue to decrease consistently and are close to extinction, and *Vulnerable* – species with a sensitive status that are distributed in limited areals or areas and are subject to negative impacts.

1 2 3

**Fig. 1.** 1,2 - *Allium tripedale* Trautv., 3 - *Allium tripedale* Trautv. *var. alba* Talibov T.

**Fig. 2.** *Aristolochia bottae* Jaub. & Spach - Botta zarəvəndi

More attention will be paid to annual plants because the most damage due to global climate change affects annual plants that are deprived of the opportunity to set seeds due to low rainfall, and their areal is reduced year by year.

## CONCLUSION

Thus, to eliminate critical problems in the biodiversity of the Nakhchivan Autonomous Republic due to global climate change, the importance of specially protected natural areas created in the autonomous republic, which account for more than 27%, was noted, and the taxonomic composition and rare species of fauna and flora biodiversity were shown. In the fauna biodiversity, from the reptiles, *Rhynchocalamus melanocephalus* Jan, and from the birds, *Chettusia gregaria* Pall. have been classified as CR, and 3 species: Striped Hyena, Marbled polecat, and Manul are no longer found in the area. 27 species of flora biodiversity have CR status. Along with the introduction of rare species in the Botanical Garden of the Autonomous Republic, it was decided to collect their seed materials and store them in genebanks.

## REFERENCES

**Red Book of the Republic of Azerbaijan. Second edition. Fauna.** (2013) Editorial board members: Hajiyev R.V., Musayev S.H., Hajiyev V.C., Talibov T.H., Alakbarov I.Kh., Alizade V.M. Baku: Sharg-Garb Publish. House, 680 p.

**Red Book of the Republic of Azerbaijan. Second edition** (2013) Rare and endangered plant and mushroom species. Editorial board members: Hajiyev R.V., Musayev S.H., Hajiyev V.C., Talibov T.H., Alakbarov I.Kh., Alizadeh V.M. et al. Baku: Sharg-Garb Publishing House, 676 p.

**Red Book of the Republic of Azerbaijan. Third edition** (2023) Rare and endangered flora species. Editorial board members: Kerimov Vugar, Talibov Tariyel, Ali-zade Valida, Gurbanov Elshad, et al. Baku: "Imak" printing house, 510 p.

**Red Book of the Republic of Azerbaijan Third edition. Fauna** (2023) Editorial board members: Kerimov Vugar, Talibov Tariyel, Ali-zade Valida, Gurbanov Elshad, et al. Baku: "Imak" printing house, 282 p.

**Taxonomic spectrum of the fauna of Azerbaijan (Vertebrates)** (2020) Editorial board: Talibov T.H., Gasımov R.Y., Akhundov M.M., Ibrahimov Sh.R., Najafov J.A., Guliyev G.N., Aliyev A.R., Michael Heiss. Baku: Elm ve Tehsil Publishing House, 144 p.

**Talibov T.H.** (1999) Rare animal species and their genefund protection in the Nakhchivan Autonomous Republic. Baku: Elm, 102 p.

**Talibov T.H.** (2003) The state of research on the biodiversity of flora and fauna of Nakhchivan nature. Materials of the International Symposium "Nakhchivan and Kars in every aspect", Nakhchivan: Geyret, pp.76-77

**Talibov T.H.** (2009) International categories and criteria used in determining the status of species. Nakhchivan Branch of ANAS. News, Natural and technical sciences series, Nakhchivan, No. 2, pp. 42-52

**Talibov T.H., Bayramov A.B., Maharramov M.M. et al.** (2018) Fauna of the Nakhchivan Autonomous Republic: Fish and amphibians. Nakhchivan: Ajami, 180 p.

**Talibov T.H., Mammadov A.F.** (2016) Taxonomic spectrum of the vertebrate fauna of the Nakhchivan Autonomous Republic. Baku: Mualllim Publishing House, 76 p.

**Talibov T.H., Ibrahimov A.Sh., Ibrahimov A.M.** (2021) Taxonomic spectrum of the flora of the Nakhchivan Autonomous Republic (Higher spore, gymnosperm and angiosperm plants). Baku: Shirvanneshr, 426 p.

**Talibov T.** (2021) Fauna of the Nakhchivan Autonomous Republic. Moscow. Orekhovo-Zuevo: GGTU Publishing house, 352 p.

**Talibov T., Rasulzade H.** (2021) Rare waterfowl of the Nakhchivan Autonomous Republic. SCI-CONF. COM. UA "Science and education: problems, prospects and innovations" Proceedings of VIII International Scientific and Practical Conference. Japan: Kyoto, CPN Publishing Group, p. 668-676

**ORCID:**
Tariyel Talibov: https://orcid.org/0000-0001-6455-8255

*Journal of Life Sciences & Biomedicine, vol. 4(77), No 2, p. 59-67 (2022)*

# Taxonomic composition and distribution of oat (*Avena* L.) species in Azerbaijan

**Aydin Asgarov[1*], Gunel Guliyeva[2]**

[1]*Institute of Botany, Ministry of Science and Education of the Republic of Azerbaijan, 40 Badamdar Highway, AZ1073, Baku, Azerbaijan*
[2]*Genetic Resources Institute, Ministry of Science and Education of the Republic of Azerbaijan, 155 Azadlig Ave., AZ1106, Baku, Azerbaijan*

[*]***For correspondence**: askerov1@mail.ru*

Received: September 27, 2024; Received in revised form: November 20, 2024; Accepted: December 19, 2024

**The article provides information on the taxonomic composition, distribution, and importance of the species of oat (*Avena* L.) in Azerbaijan. Currently, the distribution of 9 oat species (*A.eriantha A.clauda, A.strigosa, A.barbata, A.ventricosa, A.fatua, A.sterilis subsp. ludoviciana, A.byzantina, A.sativa*) in our republic has been confirmed based on literary sources, fund and expedition materials. Seven species were collected out of nine species. During the expedition, new distribution areas of 4 species collected (*A.eriantha, A.clauda, A.barbata, A.fatua*) were discovered. The data on the priority names of species, major synonyms, distribution, main bioecological features, and was given. The status of a number of species has also been clarified in the article. The article also presents the research results on the biomorphological assessment of species based on descriptor data. Species distribution was mapped using the DIVA-GİS computer program.**

***Keywords:** Azerbaijan, oat, area, biotope, species, genus, systematics*

## INTRODUCTION

Currently, 25 species of oat (*Avena* L.) are distributed mainly in the ancient Mediterranean countries (Loskutov, 2007). 12 species of oat have been recorded in the Caucasus (Grossheim, 1939), 18 in the former USSR (Rozhevitz, 1934), 10 in Eastern Europe (Tsvelev, 1976), 8 in Armenia (Gabrielyan, 2009), and 7 in the flora of Iran (Sheidai et al., 2002). "Flora of Azerbaijan" (Karyagin, 1950) provides information about 11 species and 17 genotypes of the genus Avena L. Subsequently, S. Musaev (Musaev, 1971, 1991) and other botanists identified several additional oat species (*A.strigosa, A.hirtula, A.ventricosa, A.byzantina, A.orientalis, A.sterilis*) in Azerbaijan. Recent studies have identified the distribution of 15 oat species in Azerbaijan (Asgarov, 2016).

There are differing opinions among scientists regarding the macrotaxonomic classification of the genus, specifically its division into subgenera and sections. Some botanists have divided the genus into subgenera and sections (Malzew, 1930; Loskutov, 2007; Fu Y.-B., 2018).

A review of the literature reveals that oat species identification has been based on various approaches, including biochemical (Shelukhina et al., 2008), karyological (Rajhathy and Morrison, 1959), palynological (Ladizinsky and Zohary, 1971; Coffman, 1977), anatomical (Seyfi and Zarinkamar, 2007), molecular-genetic (Kubiak, 2009; Peng et al., 2010), micromorphological studies of seeds (Baum and Hadland, 1975), and macromorphological studies (Ladizinsky, 2012).

The main purpose of this study is to determine the taxonomic composition of oat species (*Avena* L.) distributed in Azerbaijan, study their botanical and geographical positions, and investigate their potential uses based on fund and expedition data.

https://doi.org/10.59849/2710-4915.2024.2.59
Available online 31 December 2024

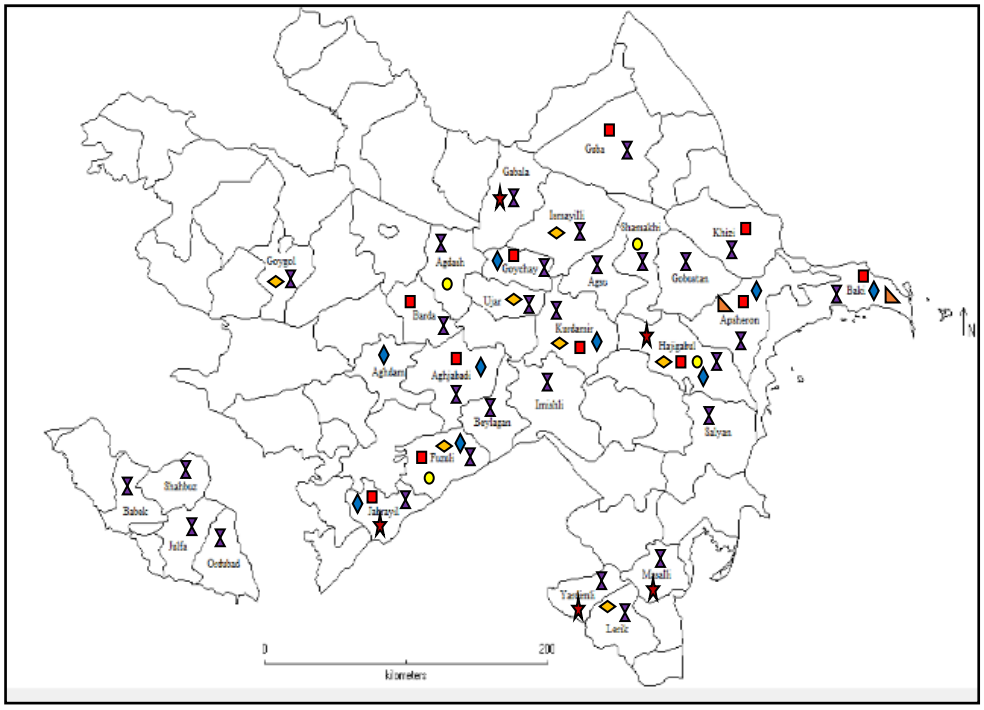


**Fig. 1.** Distribution map of collected species**:**
■ - *A.eriantha*, ○ - *A.clauda*, ♦ - *A.barbata*, ◣ - *A.ventricosa*, ◆ - *A.fatua*, ⧗ - *A.sterilis subsp. ludoviciana*, ★ - *A.sativa*

## MATERIALS AND METHODS

Comparative morphological, floristic, biomorphological, systematic, phytocenological, and experimental methods were employed in this research.

During expeditions to various regions of Azerbaijan from 2019 to 2024, herbarium materials of oat species were collected, analyzed, and identified under controlled conditions. Herbarium samples stored in the Herbarium collections of the Institute of Botany of MSERA (BAK) and the Institute of Genetic Resources (AGRI) were analyzed.

The International Botanical Code (Austria, Vienna, 2005) and international databases (WFO, IPNI) were used as references for clarifying nomenclature issues. The works of Karyagin (Karyagin, 1950), A.Asgarov (Asgarov, 2016) and S.Musaev (Musaev, 1991) were consulted for species identification.

Species distribution was mapped using the DIVA-Gis computer program.

The distribution of species of the genus *Avena* L. in Azerbaijan is given in the botanical-geographical regions adopted by "Flora of Azerbaijan" (Prilipko, 1950) and A.M.Asgarov (Asgarov, 2016).

## RESULTS AND DISCUSSION

In order to study the distribution and bioecological characteristics of Oat species in Azerbaijan, monitoring was carried out in different areas distinguished by certain ecogeographical characteristics. Furthermore, recent studies have documented the distribution of 9 oat species in semi-desert regions, sandy soils, arid and rocky slopes, and areas up to the middle mountain range in the flora of Azerbaijan. A distribution map of collected species was given (Figure 1).

**Genus *Avena*** L. 1753, Sp.Pl. :79; id. 1754, Gen. Pl., ed. 5: 34

Lektotip: *A.sativa* L.

The inflorescence is a rather open panicle or

it is one-sided. Spikelets are large, 2-4-flowered, laterally compressed; on a long, often curved pedicle from the upper part. Glumes are large, 7-9 -nerved, lemma lanceolate Lemma serrate at the summit, 2-toothed or 2-awned, with a stout awn from the back, more rarely awnless. Annual.

**Subgenus *Avena***

I. **Sect. *Aristulatae***

**1. *A.eriantha* Durieu** 1845, in Duchartre, Rev. Bot. 1: 360; Asgarov 2016, The plant world of Azerb. :116. - *A.pilosa* Bieb., 1819, Fl. Taur.-cauc., III Suppl.: 84; Karyagin 1950, Fl. of Azerb., I:204; Loskutov 2007, Oat (*Avena* L.).: 101. - Soft-flowered oat.

Typus: Algeria ("les memes lieux que *A.clauda*").

Annual. It is distributed in sub desert zones of Efemerli, dry grass, clay and stony, sandy places and in the slope, fields, roadsides. It blooms in April and bears seeds in May (Fig. 2).

Absheron, Samur-Shabran lowland, Gobustan, Bozqir plateau, Kur-Araz lowland, Kura plain.

Type in The Eastern Mediterranean. 2n=14.

During the expedition, a new distribution area of this species was discovered: Guba distr., Dagli vill., roadside, N41°22'22", E48°30'05", H 651m.

The following populations of the *A.eriantha* species have been discovered in other areas of the republic: Absheron distr.: Digah vill., meadow, N40º29'52", E49º52'47", H 25 m; Mehdiabad road, N40º29'42", E49º52'42", H 30 m; Gala-Turkan road, roadside, N40°25'32", E50°13'50", H 8 m; Zira vill., roadside, N40°21'38", E50°16'33", H -14 m; Novkhani road, roadside, N40º31'10", E49º48'11", H 24 m.; Binagadi distr., around the Vegetable Institute, roadside, N40º31'06", E49º52'08", H 44 m.; Hajigabul distr.: Pirsaat vill., roadside, N40°02'.25", E49°02'27" H 76 m; Qizilburun vill., roadside, N39°59'18", E49°12.28", H 15 m; Navai vill., roadside, N40°02'01", E49°05'13", H 45m; Kurdamir road, roadside, N40°11'25", E48°35'30", H-12 m; Khizi distr., Bakhishli vill. surroundings, forest, N40°54'07", E48°59'10", H 778 m; Goychay distr., Mirzahuseynli vill., N40°39'13", E47°39'31", H 167 m; Agjabadi distr., surroundings of Aghgol reserve, N39°57' 16", E47°33'24", H 28 m; Barda distr., Yeni Tashkent vill., mowing field, N40°23'31", E47°02' 05", H 132 m.; Jabrayil distr., Chocuq Marcanli, the edge of the sowing area, N 39°23'35", E 47°18'18", H 151m.; Fuzuli distr., Alkhanly vill., hayfield, N 39°35'27", E 47°20'13", H 270 m. (Fig. 2).

It is used as livestock feed with other annual plants in pastures. After inflorescence and seed, its nutritional value decreases (Gadzhiev, 1965).

**Fig. 2.** *A.eriantha* -Soft-flowered oat. (Barda district, Yeni Dashkend village, 17.05.2023).

**2. *A.clauda* Durieu** 1845, in Duchartre, Rev. Bot. 1: 360; Karyagin 1950, Fl. of Azerb., I:204; Loskutov 2007, Oat (*Avena* L.):101; Asgarov 2016, The plant world of Azerb.:116. - Suspicious o.

Typed in Algeria, the supposed isotype: "Algerie, Mascara, 1844, Durieu" (LE).

Annual. It is distributed in the lowlands and foothills, on dry lands and on the slopes of semi-desert zones. It blooms and bears seeds in May.

Absheron, Kur-Araz lowland, Greater Caucasus (Guba).

Type in The Ancient Mediterranean. 2n=14.

During the expedition, a new distribution area of this species was discovered: Shamakhi distr., Meysariyya vill., roadside, N40°38'47", E48°37'29", H 782 m.

Five populations of the *A.clauda* species have also been discovered in other areas of the republic: Agdash distr.: Khosrov vill., roadside, N40°37'19", E47°34'27", H 40 m; Shordahna vill.,

roadside, N40°37'25", E47°31'57", H 36 m; Hajigabul distr., Qizilburun vill., roadside, N39°59'18", E49°12.28", H 15 m; Fuzuli distr., Ashagi Kurdmahmudlu vill., hayfield, N 39°35'21", E 47°28'33", H 172m.; Fuzuli distr., Alkhanly vill., hayfield, N 39°35'27", E 47°20'13", H 270 m. (Fig. 3). The nutritional value of the plant is low, due to its low prevalence (Gadzhiev, 1965).

**Fig. 3.** *A.clauda* - Suspicious o. (Fuzuli district, Alkhanly village, 20.05.2024)

**3. *A.strigosa* Schreb.** 1771, Spicil. Fl. Lips.: 52; Loskutov 2007, Oat (*Avena* L.). :105; Asgarov 2016, The plant world of Azerb.:116. – Hard hairy o.

Typus: Germany (Leypsiq) ("Inter *Avenam sativam* frequens occurrit, neglecta agricolisque ignota"). Type in Germany (Munich).

Annual. It is distributed on the coastal sands of Absheron, Lankaran. It blooms in May and bears seeds in July.

Type Mediterranean. 2n=14.

**4. *A.barbata* Pott ex Link**, 1800, Journ. Bot. (Götting.) 2:315; Karyagin 1950, Fl. of Azerb., I:205; Loskutov 2007, Oat (*Avena* L.). :106; Asgarov 2016, The plant world of Azerb.:116. - *A.wiestii* Steud. 1854, Syn. Pl.Glum. 1: 231; Karyagin 1950, Fl. of Azerb., I:206; Loskutov 2007, Oat (*Avena* L.). :104; Asgarov 2016, The plant world of Azerb.:116. - *A.malzewii* Tzvel. 1993, Bot. jour. 78, 10: 89; Asgarov 2016, Flora of Azerb.:116.- *A.barbata* var. *caspica* Hausskn. 1894, Mitt. Thüring. Bot. Ver., N. F. 6:41, 45. - *A.hirtula* auct. non Lag.: Musaev, 1969, Reports of the Acad. of Sciences of Azerb., 25, 10: 61. - *A.hirtula* Lag. 1816, Gen. Sp. Pl.:4; Loskutov 2007, Oat (*Avena* L.). :104. - Slender wild o.

Typus: It is considered a specimen known in Portugalia ("wachst in deutschen Garten"). According to the records of N. Tsvelev, this species was described in Egypt (Tsvelev, 1976).

Annual. It is distributed in the lowlands, sometimes in the lower mountain belt, coastal sands, river beds, on dry rocky slopes, and on the edges of crops. It blooms in May and bears seeds in July.

Absheron, Samur-Shabran lowland, Gobustan, Alazan-Ayrichay valley, Kura-Araz lowland, Kura plain, Lesser Caucasus (south), Diabar, Lankaran lowland.

Type Mediterranean. 2n=28.

During the expedition, 2 new distribution areas of this species were discovered: Agjabadi distr., Khojavand vill., forest surroundings, N40°02'20", E47°24'17", H 31m.; Khachmaz region, Agatala village, right bank of the Shollar water pipeline, railway area, garden areas.

The following populations of the *A.barbata* species have been discovered in other areas of the republic: Balakhani, between oil rigs, N40º27'57", E49º56'23", H19 m; Mehdiabad-Pirshaghi road, roadside, N40°31'52", E049°52'44", H 29 m; Zira vill., roadside, N40°21'38", E50°16'33", H -14 m; Pirallahi distr., seaside, N40°27'16", E50°20'05", H-9m; Mardakan settlement, roadside, N40°27'34.576", E50°10'11.237", H8m; Pirallahi distr., Chilov island, fieldside, N40°19'16", E50°36'10", H-43 m; Yasamal distr., around the Residential Complex, roadside, N40°22'42", E49°47'52", H 98 m; Goychay distr., Garamaryam vill., roadside, N40º37'07", E48º01'08", H162 m; Hajigabul distr., Qizilburun vill., roadside, N39°59'18", E49°12.28", H 15 m; Aghdam distr., Abdal Gulabli village, N39°52'57", E46°56'48", H554m.; Jabrayil distr., Chocuq Marcanli, the edge of the sowing area, N39°23'35", E47°18'18", H151m.; Fuzuli-Khojavand road, meadow, N39°36'13", E47°07'39", H462 m. (Fig.4).

This species of oat is considered to be a good pasture and hay crop (Gadzhiev, 1965).

Note: The species *A.malzevii* Tzvel. was described from Azerbaijan. It is described from Azerbaijan. Typus: "Баку, 2 V 1893, В. Липский" (LE).

**Fig. 4.** *A.barbata* – Slender wild o. (Agjabadi district, Khojavand village, 16.05.2023).

Russian botanist Lipski collected *A.barbata* var.*caspica* Hausskn. as a genotype of *A.barbata* on the basis of a herbarium specimen, collected around Baku in 1893. N. Tsvelev studied the specimens stored in St. Petersburg and accepted this species as an independent species. According to Tsvelev, the plant known as *A.hirtula* auct.non Lag. is a species *A.malzevii* Tzvel. However, the WFO currently lists this species as a synonym of *A.barbata*.

**5. *A.ventricosa* Bal. ex Coss.** 1854, Bull. Soc. Bot. Fr. I: 14; Musaev 1991, Cereals of Azerb. :102; Loskutov 2007, Oat (*Avena* L.). : 102; Asgarov 2016, The plant world of Azerb.:116. – *A.bruhnsiana* Grun. 1867, Bull.Soc.Nat. Moscou, 40, 4: 458; Karyagin 1950, Fl. of Azerb., I:205; Loskutov 2007, Oat (*Avena* L.) :102; Asgarov 2016, The plant world of Azerb.:116. – Blistered o.

Typus: “Lieux incultes de l`Algerie occidentale”, Balansa.

Annual. It is distributed in coastal sands. 2n=14.

Absheron.

During the expedition, 4 populations were discovered: Balakhani, between oil rigs, N40º27'57", E 49º56'23", H 19 m; Zira vill., roadside, N40°21'38", E50°16'33", H-14 m; Pirallahi distr., seaside, N40°27'16", E50°20'05", H-9m; Pirallahi distr., Chilov island, fieldside, N40°19'16", E50°36'10", H-43 m. (Fig.5).

**Fig. 5.** *A.ventricosa* – Blistered o. (Khazar district, Zira village, 06.05.2023)

The distribution area is not large. Moderately significant as a forage crop.

Note: *Avena bruhnsiana* was described from Azerbaijan. It was considered an endemic species.

Typus: "Mare Caspi, Pyralaia, 24 IV 1864, A.Bruhns" (LE).

L.F. Gruner collected this species from Absheron (Artyom Island) in 1867 and described it as an endemic species for Azerbaijan under the name *Avena bruhnsiana* Grun. Rajhathy insisted that this species was a species of Shingles oat (*A.ventricosa* Bal.). However, as a result of the analysis of collected and herbarium specimens, it became clear that *A.bruhnsiana* Grun. is an endemic plant to the flora of Azerbaijan.

According to S.Musaev (Musaev, 1971), in Absheron, in the coastal sands can be found a species of oat - *A.ventricosa* Bal. which differs by its short glumes and callus, along with *A.bruhnsiana* Grun. S. Musaev (Musaev, 1971) showed that this species is distributed in other regions of the Caucasus too.

The author of a monograph of the genus "Oat (*Avena* L.) distribution, taxonomy, evolution and breeding value" I.Loskutov concludes that the primary distribution center of the *A.ventricosa*

Bal. ex Coss. species described in Algeria is Algeria, near the city of Oran, at an altitude of 200 m above sea level (Loskutov, 2007). According to unconfirmed data, the second center of the species is Iran.

Loskutov did not mention in his monograph the distribution of this species in Azerbaijan.

However, the WFO currently lists this species as a synonym of *A.ventricosa*.

**Sect. II. *Denticulatae***

**6. *A.fatua* L.** 1753, Sp.Pl.:80; Karyagin 1950, Fl. of Azerb., I:207; Loskutov 2007, Oat (*Avena* L.). :109; Asgarov 2016, The plant world of Azerb.:116. - *A.meridionalis* (Malz.) Roshev 1932, Fl. Turkm., I, 105; Karyagin 1950, Fl. of Azerb., I:206; Asgarov 2016, The plant world of Azerb.:116. - *A.fatua* L. subsp. *meridionalis* Malz. 1930, Works on applied botany, genetics, selection 38:304, табл. 45; Tsvelev 2006, Consp. of the fl. of Caucasus, II:286. - Wheat o.

Typus: Европа ("in Europae agris inter segetes").

Annual. It is distributed in the lowlands to the middle mountain belt, in weeds, sowings, fields, and roadsides. It blooms in June and bears seeds in July.

Absheron, Samur-Shabran lowland, Greater Caucasus (Guba), Gobustan, Alazan-Ayrichay valley, Kura-Araz lowland, Kura plain, Diabar, Lankaran lowland.

Type Polyarctic type. 2n=42.

During the expedition, 2 new distribution areas of this species were discovered: Ismayilli distr., İvanovka vill., vineyard area, N40°45'06", E48°02'07", H768 m; Zagatala district, Jar village, backyard, roadside, N41°39'31", E46°40'22" H709 m.

6 populations of *A.fatua* species have been discovered in other areas of the republic: Goygol distr., Togana vill., rocky and grassy slopes, N40°26'17", E046°19'24", H1144 m; Lerik dist., Galasar vill., bush, N38°41'29", E048°23'54", H1360m; Ujar distr., Alpi vill., roadside, N40°29'25", E47°41'27", H14m; Hajigabul distr., Pirsaat vill., roadside, N40°02'25", E49°02'27" H76 m; Kurdamir road, roadside, N40°11'25", E48°35'30", H-12 m; Fuzuli distr., Alkhanly vill., hayfield, N 39°35'27", E 47°20'13", H270 m.

Valuable food and fodder plant and is used by livestock. Occasionally used as a cereal substitute (Gadzhiev, 1965).

**7. *A.sterilis subsp. ludoviciana* (Durieu) Nyman** 1882, Consp. Fl. Eur. : 809. – *A.ludoviciana* Durieu, 1855, Act. Soc. Linn. Bordeaux, 20:41; Karyagin 1950, Flora of Azerb., I:208; Loskutov 2007, Oat (*Avena* L.) :109; - *A.persica* Steud. 1854, Syn.Pl.Glum. 1: 230; Asgarov 2016, The plant world of Azerb.:116. - *A.trichophylla* C. Koch 1848, Linnaea, 21:393; Karyagin 1950, Fl. of Azerb., I:208; Asgarov 2016, The plant world of Azerb.:116. -Ludovic o.

Typus: France.

Annual. Distributed in the middle mountain belt, sowing areas, roadsides. It blooms in April and bears seeds in July.

It is found in all regions of Azerbaijan.

It is of the ancient Mediterranean type. 2n=42, 44.

During the expedition, several populations from Azerbaijan were discovered: Baku city: Khatai distr., Mehmandarov street, roadside, N40°22'25", E49°57'14", H70 m; Masazir-Novkhani road, N40º30'26", E49º45'14", H 12 m; Binagadi distr., around the Vegetable Institute, roadside, N40º31'06", E49º52'08", H44 m.; Mehdiabad road, N40º29'42", E49º52'42", H30 m; Pirallahi distr., Chilov island, fieldside, N40°19'16", E50°36'10", H-43 m; Khizi distr., Bakhishli vill. surroundings, forest, N40°54'07", E48°59'10", H778 m; Imishli distr., roadside, N39º45'13", E047º53'53", H16 m; Kurdamir distr., Girdimanchay surroundings, river bank, N40°09'42", E48°03'48", H-13 m; Kurdamir distr., Khinishli vill., meadow, N40°21'16", E48°16'02", H 6 m; Hajigabul distr.: Pirsaat vill., roadside, N40°02'.25", E49°02'27" H76 m; Qizilburun vill., roadside, N39°59'18", E49°12.28", H 15 m; Guba distr: Gonaqkend vill., roadside, N41°04'17", E48°36'07", H1063 m; Vladimirovka vill., roadside, N41°23'20", E48°32'40", H518m; Barda distr., Lanbaran vill., mowing field, N40°12'17", E47°17'49", H25 m.; Salyan distr., the edge of the reserve, N39º33'54", E49º00'23", H-25 m; Ismayilli distr., İvanovka vill., vineyard area, N40°45'06", E48°02'07", H768 m; The road to Agsu, N40º41'07", E48º26'41", H868 m; Shamakhi distr., Madrasa vill., vineyards, N40º36'17", E48º33'708", H 673 m; Lerik distr., Divagaj vill., xerophytic grass and shrubs, N38º42'54", E48º31'37", H1470 m; Lerik

distr., Gunashli vill., forest, N38º46'25", E48º24'49", H1085 m; Yardimli distr., upper part of Pirembel vill., Canak area, N38º55'03", E048º07'02", H1400 m; Exit of Gobustan distr., roadside, N40º31'31", E48º51'28", H721 m; Goygol distr., Togana vill., rocky and grassy slopes, N40°26'17", E046°19'24", H1144 m; Nakhchivan: Ordubad distr., around Duyulu vill., N38º55'34", E46º00'17", H1020 m; Shahbuz distr., the end of Kolani vill., N39º27'19", E45º41'07", H1428 m; Babek distr., Nehram vill., N39º07'13", E45º28'07", H833 m; Julfa distr., around Yayci vill., N38º57'39", E45º42'54", H 764 m; Beylagan distr., Allahyarli vill., surrounding area of the agricultural field, N39°44'19", E47°35'58", H81 m; Agjabadi distr., surroundings of Aghgol reserve, N39°57' 16", E47°33'24", H28 m; Jabrayil distr., Chocuq Marcanli, the edge of the sowing area, N39°23'35", E47°18'18", H151 m.; Fuzuli district, edge of the Kondalen reservoir, hayfield, N39°36'9.774, E47°11'43.867 , H401 m.; Fuzuli-Khojavand road, meadow, N39°36'13", E47°07'39", H462 m.; Fuzuli distr., Ashagi Kurdmahmudlu vill., hayfield, N39°35'21", E47°28'33", H172 m. etc. (Fig. 6).

Valuable fodder crop. It is cultivated as a fodder crop by locals in the Western Caucasus (Gadzhiev, 1965).

**Fig. 6.** *A.sterilis subsp. ludoviciana* - Ludovic o. (Beylagan district, Allahyarli village. 15.05.2022)

Note: The species *A.trichophylla* C. Koch was described from Azerbaijan (Shirvan Plateau).

Typus: "In der schirwan`schen Ebene auf Kalk, Mergelboden 500-700` hoch, C.Koch" (B?).

In the flora of Eastern Europe (Tsvelev, 1976), this species is described from the Shirvan steppe in the South Caucasus. During the determination of the description of the species ("İn der Schirwan`schen Ebene auf Kalk, Mergelboden 500-700` hoch, C.Koch") (Tsvelev, 2006), it becomes clear that it is described from the territory of Azerbaijan.

**8. *A.byzantina* C. Koch** 1848, in Linnaeae, 21: 392; Loskutov 2007, Oat (*Avena* L.).:110; Asgarov 2016, The plant world of Azerb.: 116. - Byzantine o.

Typus: Described from Turkey. "İn der Umgegend von Konstantinopol unter dem Getreide auf Mergelund Kalkboden, C.Koch" (B).

Annual. Lesser Caucasus (east), Lankaran lowland. It blooms in June and bears seeds in August. Cultivated as a fodder crop. 2n=42.

**Note:** *A.byzantina* species was described in 1848 by Karl Cokh around the city of Istanbul. Musaev in "A new species of oat in the flora of the USSR" (Musaev, 1971) recorded that this species is similar to the species of hairy oat (*A.trichophylla* C. Koch) in terms of morphological features (hairy leaves, stem nodes, etc.). The only difference from this species is the absence of a slug-shaped hole at the lower part of the flowers on the spike. Wild oat has a sloping hole at the base of the lower flower.

Byzantine oat differs from cultivated oat by the presence of a small holl at the base of the flower and its resistance to drought and fungal diseases. Distributed in Azerbaijan in the Lesser Caucasus (Tartar region) and Talish (Musaev, 1971).

**9. *A.sativa* L.** 1753, Sp. Pl.: 79; Karyagin 1950, Fl. of Azerb., I:207; Loskutov 2007, Oat (*Avena* L.). :110; Asgarov 2016, The plant world of Azerb.:116. - *A.macrantha* (Hack.) Malzev 1934, USSR weed plant, I, 206; *A.fatua* subsp. *macrantha* Malzev 1930, Oats and wild oats, 309; Karyagin 1950, Fl. of Azerb., I:208; Rozhewicz 1934, Fl. of USSR, II:266; Grossheim 1939, Fl. of Caucasus, I: 211. - *A.orientalis* Schreb. 1771, Spic. Fl. Lips. :52; Asgarov 2016, The plant world of Azerb.:116. - Grass o.

Typus: London. Described from the Mediterranean Sea.

Annual. It is spread in all regions of Azerbaijan. It blooms in June and bears seeds in August.

It is a Mediterranean area. 2n=42.

Several populations from Azerbaijan were discovered during the expedition: Yardimli distr., the upper part of Pirembel vill., Canak area, N38º55'03", E048º07'02", H1400 m; Hajigabul distr., Navai vill., roadside, N40°02'01", E49°05'13", H45m; Gabala distr., right bank of Demiraparan river, stony and sandy places, N40°58'37", E47°52'14", H972 m.; Masalli distr., Sharafa vill., roadside, N39°04'32", E48°41'25" H -15 m.; Jabrayil distr., Chocuq Marcanli, the edge of the sowing area, N39°23'35", E47°18'18", H151m. (Fig. 7).

**Fig. 7**. *A.sativa* - Grass o. (Hajigabul district, Navai village, 18.05.2022)

*A.sativa* L. has been used as food and fodder since ancient times. It is used in the preparation of porridge, bread, snacks, and baby food. In industrialized countries, oat seeds are mainly used as animal feed, especially for horses, but also livestock and other animals.

## CONCLUSIONS

As a result of the conducted research, the distribution of 9 species of the genus Avena L. in Azerbaijan has been determined. The work "Flora Azerbaijan" lists 11 species of the genus. Several species (*A.bruhnsiana, A.wiestii, A.meridionalis, A.macrantha, A.trichophylla*) have been transferred to synonymy of other species. New distribution areas of 4 species (*A.eriantha, A.clauda, A.barbata, A.fatua*) were discovered. A distribution map of the collected species was given.

## REFERENCES

**Asgarov A.M.** (2016) The plant world of Azerbaijan. TEAS PRESS, p. 444 (in Azerbaijani)

**Baum B.R., Hadland V.E.** (1975) The epicuticular waxes of glumes of *Avena*: a scanning electron microscopic study of the morphological patterns in all the species. *Can. J. Bot.*, **53:** 1712-1718.

**Coffman F.A.** (1977) Oat history, identification and classification. *Technical Bulletin*, **N1516:** 356 p.

**Fu Y.-B.** (2018) Oat evolution revealed in the maternal lineages of 25 *Avena* species. *Scientific Reports*, **8 (1):** 1-8.

**Gabrielyan E.Ts.** (2009) *Avena* L. Flora of Armenia. A.: National Academy of Sciences of Armenia, p.153-157(in Russian).

**Gadzhiev V.İ.** (1965) Forage plants of meadows and pastures of Azerbaijan (Grains and legumes), Baku: 103-107 (in Azerbaijani)

**Grossheim** A.A. (1939) Flora of Caucasus. Vol. **I:** 205-212 (in Russian).

**Karyagin İ.İ.** (1950) Flora of Azerbaijan Baku: Publ. house of Academy of Sciences of Azerbaijan SSR, **vol. I:** 203-210 (in Russian).

**Kubiak K.** (2009) Genetic diversity of *Avena strigosa* Schreb. ecotypes on the basis of isoenzyme markers. *Biodiv. Res. Conserv.*, **15:** 23-28.

**Ladizinsky G.** (2012) Studies in oat evolution. Springer: *Briefs in Agriculture*, 87 p.

**Ladizinsky G., Zohary D.** (1971) Notes on species delimination, species relationships and polyploidy in *Avena* L. *Euphytica*, **20:** 380-395

**Loskutov I.G.** (2007) Oat (*Avena* L.). Distribution, taxonomy, evolution and breeding value. St-P.: SSC RF VIR. 336 p. (in Russian).

**Malzew A.I.** (1930) Ovsyugi i ovsy. Sectio Euavena Griseb. (Wild and Cultivated Oats. Sectio Euavena Griseb.). *Works of Applied Botany and Plant Breeding. Supplement*, **no. 38.**

**Musaev S.G.** (1971) A new species of Oat of the flora of the USSR. Baku: Elm, p. 71-72 (in Azerbaijani)

**Musaev S.G.** (1991) Cereals of Azerbaijan. Baku: Elm, 421 p. (in Russian).

**Musaev S.G., İsaev Y.M.** (1971) *Avena bruhnsiana* Grun. (Bruns o.) - Endemic species of the flora of Azerbaijan. Reports of the Academy of Sciences of Azerbaijan. SSR, **27:** 64-65 (in Russian).

**Peng Y.-Y., Baum B.R., Ren C.-Z., Jiang Q.-T., Chen G.-Y., Zheng Y.-L., Wei Y.-M.** (2010) The evolution pattern of rDNA ITS in *Avena* and phylogenetic relationship of the Avena species (*Poaceae: Aveneae*). *Hereditas*, **147 (5):** 183-204.

**Prilipko, L.İ.** (1950) Flora of Azerbaijan. Baku: Publ. house of Academy of Sciences of Azerbaijan USSR, vol. I: 370 p. (in Russian).

**Rajhathy T., Morrison J.W.** (1959) Chromosome morphology in the genus *Avena*. Canadian *Journal of Botany*, **37(3):** 331-337.

**Rozhewicz R.Yu.** (1934) *Avena* L. Flora of USSR. Leningrad: Publ. house of Academy of Sciences of USSR, **vol. II:** 259-270 (in Russian).

**Seyfi Z., Zarinkamar F.** (2007) Anatomical Studies of Some *Avena* species in Iran. *Rostaniha*, **8 (2(29)):** 186.

**Sheidai M., Koobaz P., Termeh F., Zehzad B.** (2002) Phenetic studies in Avena species and populations of iran. *Journal of Sciences, Islamic Republic of Iran*, **13(1):** 19-28.

**Shelukhina O.Yu, Badaeva E.D., Brezhneva T.A., Loskutov I.G., Pukhalsky V.A.** (2008) Comparative analysis of diploid species of *Avena* L. Using cytogenetic and biochemical markers: *Avena pilosa* M. B. and *A.clauda* Dur. *Russian Journal of Genetics*, **44(9):** 1087-1091.

**Tsvelev N.N. (1976)** *Avena* L. Flora of the European part of the USSR. Leningrad: Publ. house of Academy of Sciences of USSR, **vol. I:** 190-196.

**Tsvelev N.N. (2006)** Conspectus of the flora of Caucasus. Saint-Petersburg: Publishing house Saint-Petersburg university, **vol. II:** 285-288.

**ORCIDS:**
Aydin Asgarov: https://orcid.org/0000-0003-2006-5832
Gunel Guliyeva: https://orcid.org/0000-0003-1858-5927

*Journal of Life Sciences & Biomedicine, vol. 6(79), No 2, p. 68-74 (2024)*

# Characteristics of general and phytopathogenic mycobiota of dry subtropical fruit plants cultivated in Azerbaijan

**Konul Bakshaliyeva[1,2*], Gultekin Arabova[1], Sevil Suleymanova[2], Panah Muradov[1]**

*[1]Institute of Microbiology, Ministry of Science and Education of the Republic of Azerbaijan, Baku, Azerbaijan*
*[2]Research Institute of Fruit and Tea Cultivation, Ministry of Agriculture of the Republic of Azerbaijan, H.B. Zerdabi Settl., AZ4035, Guba, Azerbaijan*

[*]***For correspondence*****:** *konul.baxsh@mail.ru*

Received: October 5, 2024; Received in revised form: October 30, 2024; Accepted: December 15, 2024

**Against the backdrop of global climate change, certain processes also occur in the mutual relations between plants and fungi, which was investigated in order to clarify this, based on the specific weight of phytopathogens among fungi involved in the formation of the mycobiota of some fruit plants cultivated in Azerbaijani conditions. It became clear that a total of 127 species were involved in the formation of the mycobiota of 11 plant genera and cultivars. 66.9% of the recorded species are those that cause one or another pathology in plants. When compared with previous studies, it was determined that some of these species are new to these areas. Among the reasons for this are the changes in the migration of fungi due to the global problems in nature.**

***Keywords:*** *Fruit plants, general mycobiota, phytopathogens, climatic factors*

## INTRODUCTION

Climate change and food shortages remain serious threats only to people. Although climate change is generally a natural phenomenon, one of the factors causing the currently mentioned global climate change is the result of intensive human intervention in nature (greenhouses, automobile gases, factory waste, etc.) (Stern, 2006). Thus, as an example, it is enough to say what harmful effects on the human body are caused by harmful gases emitted into the atmosphere by cars in megacities and greenhouses used to grow fruits and vegetables to meet the population's needs for food products. However, climate change not only negatively affects people's health but also creates a number of economic (crop loss) and environmental problems (floods and floods). Although adverse climate change has different effects on different sectors, the most serious impact is felt in the agricultural sector, especially those related to crop production, due to waste disposal and rising temperatures. So, in the process of evolution, plants were constantly exposed to climate changes, which were related to the amount of $CO_2$ in the atmosphere and temperature (Franks et al., 2013; Hansen et al., 2010). According to some reports, the amount of $CO_2$ in the air was 0.018% ppm, since the last ice age, about 20 thousand years ago, but now it is 0.041%, and it is expected to increase to 0.051-0.1% by the end of the century. The average global temperature increased by $4.5^0$C from that period to the first industrial revolution and after that, it increased by $0.8^o$C until the present day. It is predicted that the temperature will rise by 1-3.7ºC by the end of our century (Ciais et al., 2013). For this reason, for a long time, the changes in the life of plants caused by the increase in temperature and $CO_2$ and the adaptation of their morphological and physiological characteristics to the mentioned changes have been the focus of research (Dusenge et al., 2017). According to the research conducted in this direction, experts note that a 2ºC increase in temperature can cause a 20-25% decrease in the



https://doi.org/10.59849/2710-4915.2024.2.68
Available online 31 December 2024

productivity of some plants, primarily those used in agriculture (Gornall et al., 2010; Monaco, 2024). This is a significant loss of crop yield and its prevention is an issue that is currently of great concern to the scientific community and is an important problem that needs to be addressed. So, its occurrence leads to environmental, economic and social problems (Aragon et al., 2019). This situation is found not only in developing countries but also in developed countries. According to the assessment carried out on the climate change model, it is noted that in 2050 there could be a 15% yield loss in the production of corn in the United States, which means a financial loss of 6.7 billion dollars (Burke and Emerick, 2016; Carrraro, 2016).

It should be noted that when interacting with organisms belonging to different plant taxonomic groups (Monaco, 2024) depending on the nature of this relationship, various changes occur in the productivity of plants. The increase in temperature and the increase in the amount of $CO_2$ give additional nuances to the changes in these relations (Crous, 2019). Thus, microorganisms actively participate in the degradation and production processes occurring in nature, participate in the regulation of biodiversity in antagonistic relations with phytopathogens, and play an indispensable role in soil fertilization and productivity growth by establishing symbiotic relationships with plants. An increase in temperature or excessive humidity causes the destruction of these microorganisms and the creation of new microorganisms that will adapt to that environment, which does not pass without complications. The presence of floods, heavy rains, and sometimes, on the contrary, failure to irrigate agricultural fields despite extremely hot weather, leads to both crop loss and the reduction of microorganisms that are permanent inhabitants of agricultural fields, and the increase of those that are not characteristic for that region and the formation of various diseases in plants. Both the qualitative and quantitative indicators of the plant infected with the disease are low.

Like the rest of the world, Azerbaijan also has not escaped the negative consequences of climate change, such as heavy rainfall, drought, etc. Although these problems are not so serious in our country today, scientific measures must be taken in a timely manner to prevent negative situations that may arise in the future. At the Scientific Research Institute of Fruit and Tea Cultivation of the Ministry of Agriculture, in addition to fruit varieties belonging to folk selection, new varieties of fruits are grown, introduced from different countries and obtained through selection by local scientists, which is very important from the point of view of evaluating resistant varieties suitable for changing climate (Ağayeva, 2007; Sadıqov, 2023). One of the criteria used in the evaluation is the resistance of varieties to various diseases.

As it is known, fungi, bacteria and viruses are involved in the occurrence of diseases in plants (Nazarov et al., 2020), including fruit and berry plants. The diseases caused by fungi differ significantly from those of other groups both in number and in the amount of damage they cause (Fang et al., 2023). This has made a more comprehensive study of fungi an urgent task due to the elimination of difficulties caused by the impact of global problems. Taking this into account, the general mycobiota of various fruits cultivated in some regions of Azerbaijan, more precisely, dry subtropical fruit plants was set as a goal according to their species composition and the specific weight of phytopathogens.

## MATERIALS AND METHODS

Researches were conducted in the Absheron-Khizi and Guba-Khachmaz economic regions of the Republic of Azerbaijan. For this purpose, samples were taken from the aerial parts of dry subtropical fruit plants cultivated in the mentioned areas and analyzed according to the species composition of the fungal biota (Barsukova et al., 2005). The species composition of the fungi was determined according to the classic mycological methods (Experimental Methods, 1982), and for this, it was carried out according to the cultural-morological and some physiological characteristics of the pure cultures of the fungi separated according to the known mycological methods in standard nutrient media (Suslo-agar, Saburo agar, Potato agar, etc.). Known determinants and atlases (Bondartseva, 1998; Crous et al., 2007; Dugan, 2017; Samson et al. 2010; Watanabe, 2002) were used to determine

the species composition.

During the determination of the specific weight of the phytopathogenic species among the recorded fungi were used determinants (Horst, 2013) based on the symptoms of diseases caused by fungi as well as approaches used in the works of some authors (Crous et al., 2021).

## RESULTS AND DISCUSSION

As a result of the fungal biota analysis of more than 250 samples taken from dry subtropical fruit plants during the research period, a total of 127 fungal species were found, their distribution on individual dry subtropical fruit plants is given in table 1.

As can be seen at first glance, the number of species involved in the formation of mycobiota of fruit plants differs from each other. For example, the pistachio plant is characterized by a relatively rich and the pomegranate by a low mycobiota. Fungi recorded on these or other plants are characterized by different indicators due to other aspects, namely the specific gravity of phytopathogens, ecotrophic relationships and manifestations of ecotrophic specialization. More precisely, each plant is characterized by a specific mycobiota in some sense, so the recorded fungi can be divided into 3 groups:

1. Those without substrate specificity, i.e. those found in the majority of plants studied (on average, more than 2/3 of the plants studied);
2. Those with relative substrate specificity, that is, those found in 20-50% of the studied plants;
3. Those with substrate specificity, i.e., those found in a particular plant species under study.

When characterizing the recorded fungi according to this distribution, as well as the number of phytopathogens involved in the formation of the general mycobiota, it is clear that the number of universals is greater than in other groups, and the number of specifics is relatively small, and this ratio is generally the same for all plants(tab. 2). As for the specific weight of phytopathogens, there is a difference between plants. So, although the total weight of phytopathogens is 55.1% of registered fungi, the specific weight of phytopathogens involved in the formation of mycobiota of this or that plant varies from 51.9-65.6% and in this regard, the highest index belongs to *Elaeagnus angustifolia* L. (32/21=65.6%) and the lowest index belongs to *Ziziphus jujuba* Mill. (27/14=51.9%).

**Table 1.** Quantitative characterization of the fungi recorded during the research

| Plant species | The number of recorded species | The share of recorded total fungi, % |
|---|---|---|
| *Elaeagnus angustifolia* L. | 32 | 25.2 |
| *Pistacia vera* L. | 38 | 29.9 |
| *Prunus dulcis* Mill. | 31 | 29.1 |
| *Punica granatum* L. | 23 | 18.1 |
| *Ficus carica* L. | 35 | 27.6 |
| *Olea europaea* L. | 29 | 22.8 |
| *Ziziphus jujuba* Mill. | 27 | 21.3 |
| **Total number of fungi recorded** | 127 | 100 |

**Table 2.** Quantitative characteristics of fungi recorded according to their relation to the substrate, specific gravity of phytopathogens

| Plant species | The number of species according to their relation to the substrate | | | The number of phytopathogens |
|---|---|---|---|---|
| | Universals | Relative substrate specificity | Those with substrate specificity | |
| *Elaeagnus angustifolia* L. | 17 | 12 | 3 | 21 |
| *Pistacia vera* L. | 19 | 14 | 5 | 23 |
| *Prunus dulcis* Mill. | 14 | 13 | 4 | 18 |
| *Punica granatum* L. | 12 | 9 | 2 | 12 |
| *Ficus carica* L. | 17 | 14 | 4 | 22 |
| *Olea europaea* L. | 14 | 10 | 5 | 19 |

| | | | | |
|---|---|---|---|---|
| *Ziziphus jujuba* Mill. | 15 | 9 | 3 | 14 |
| **Total number of fungi recorded** | 61 | 42 | 24 | 70 |

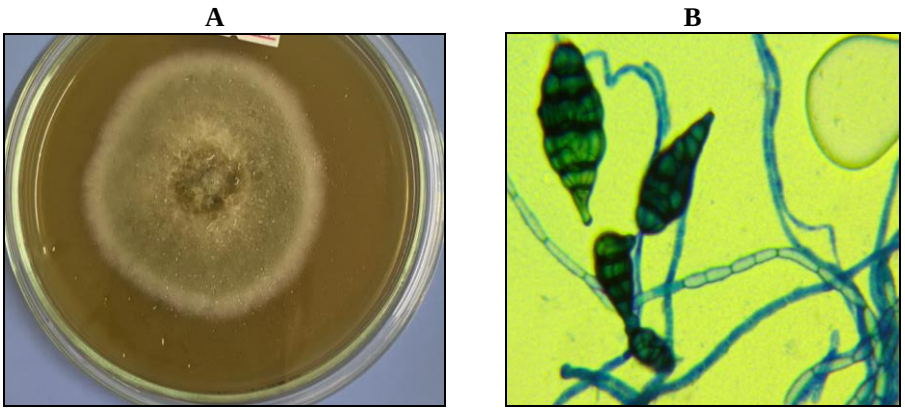


**Fig. 1.** Macroscopic (A) and microscopic (x960, B) view of the colony of the fungus *Alternaria pruni* isolated from *Pistacia vera.*

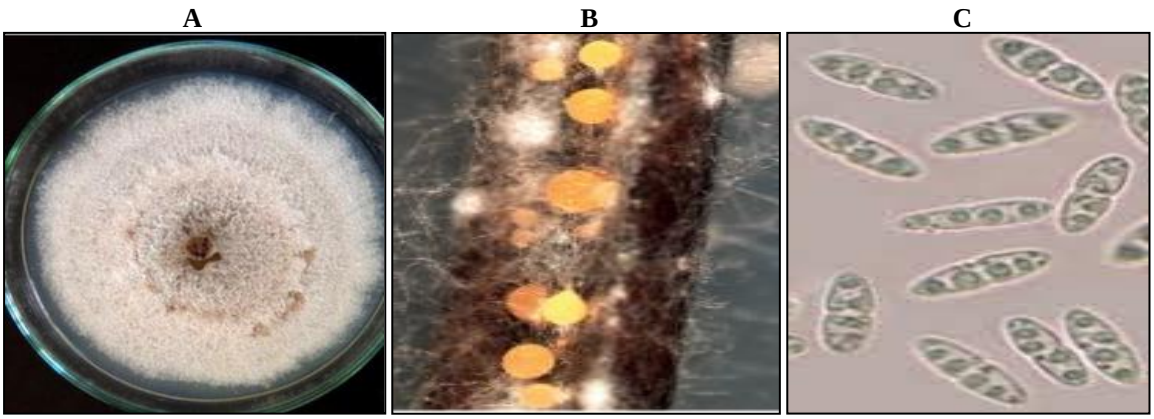


**Fig. 2.** Macroscopic (A, B) and microscopic (x960, C) view of the colony of the fungi *Diaporthe elaeagni* isolated from *Elaeagnus angustifolia.*

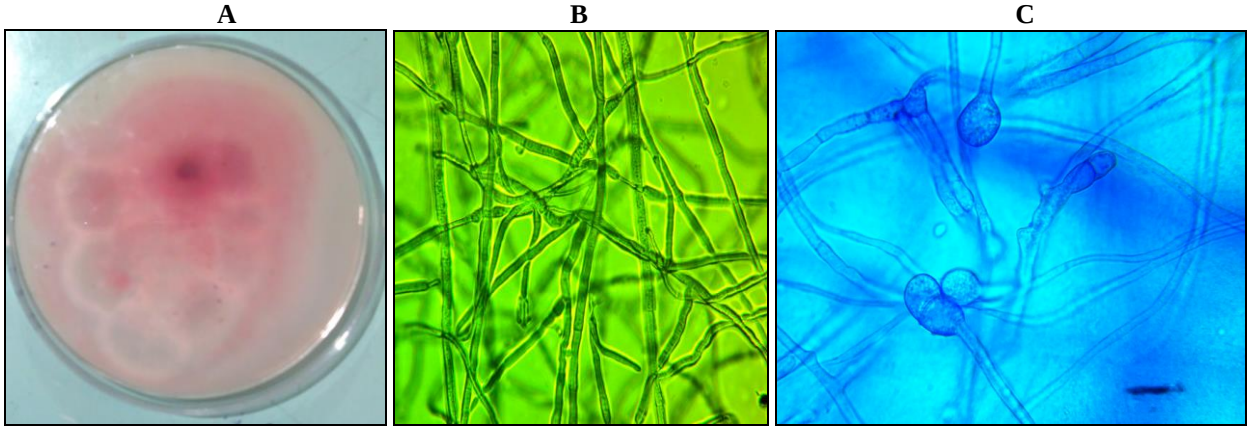


**Fig. 3.** Macroscopic (A) and microscopic (x960, B, C) view of the colony of the fungi *Fusarium equiseti* isolated from *Prunus dulcis.*

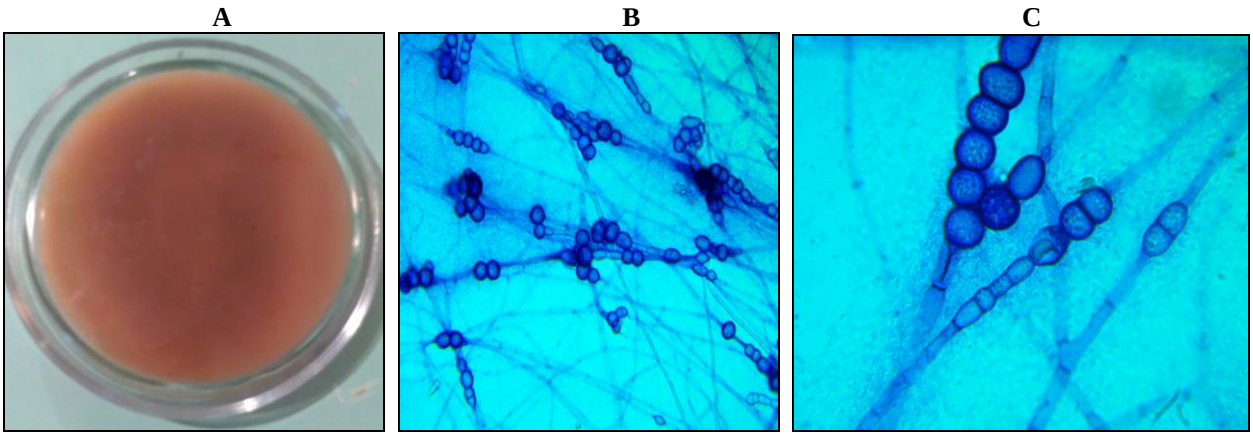


**Fig. 4.** Macroscopic (A) and microscopic (x960, B, C) view of the colony of the fungi *Fusarium xylarioides* isolated from *Punica granatum.*

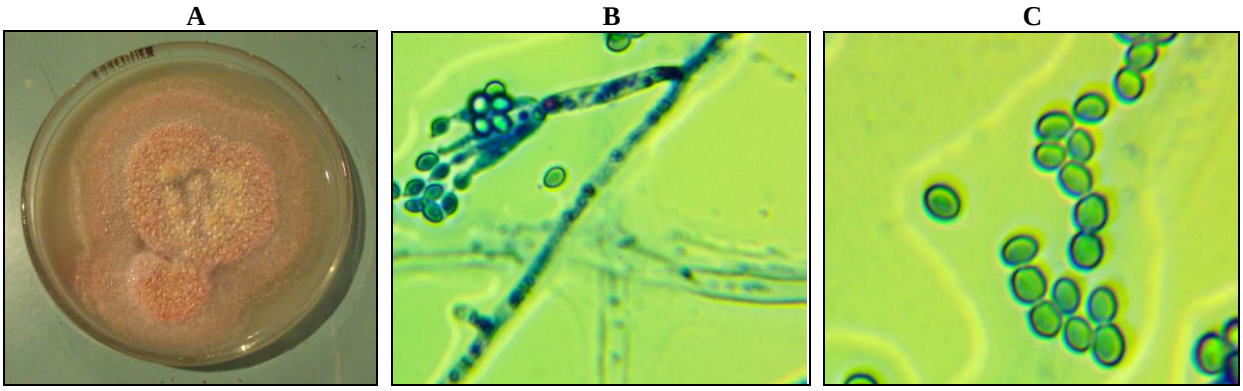


**Fig. 5.** Macroscopic (A) and microscopic (x960, B, C) view of the colony of the fungi *Paecilomyces lilacinus* isolated from *Ficus carica.*

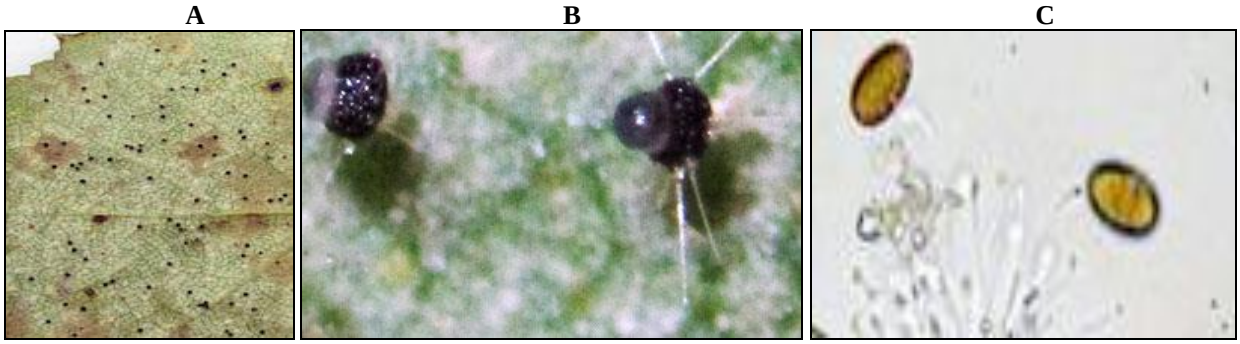


**Fig. 6.** General view of the observation form (A), sac (B) and ascospores (x960, C) on the leaf of the fungi *Phyllactinia acaciae* isolated from *Prunus dulcis.*

It should be noted that in the Republic of Azerbaijan, work on the comprehensive study of the mycobiota of dry subtropical fruit plants was carried out 17-20 years ago(Ağayeva, 2007). When we compare the fungi recorded during those studies with the fungi recorded during our research according to their species composition, it is clear that although there are no significant differences between the species involved in the formation of epiphytic mycobiota, certain

differences are revealed in phytopathogenic species. This manifests itself in the fact that fungi, which have not been registered in this or that plant, gain a new host. For example, fungi such as *Alternaria pruni* (fig. 1), *Diaporthe elaeagni* (fig. 2), *Fusarium equiseti*(fig.3), *F.xylarioides*(fig. 4), *Paecilomyces lilacinus* (fig. 5), *Phyllactinia acaciae* (fig. 6), etc. recorded in the researched plants, were not found in previous studies. The climatic factor, more specifically climate change can be mentioned as the reason, but it would not be correct to unambiguously show the quantitative expression of the influence of this factor. Thus, global climate change affects not only plants but also living things that interact with them in various aspects, including fungi. The full clarification of its nature should be the task of future research.

Thus, the results obtained in the conducted research are important from the point of view of providing the country's population with quality fruits, increasing production, increasing the quantity and quality of exported products from an economic point of view, as well as correctly predicting what will happen in the following years against the background of climate change.

**This work was carried out with the financial support of the Azerbaijan Science Foundation: Grant *№ AEF-MCGAT-2023-1(43)-13/10/3-M-10.***

## REFERENCES

**Aghayeva T.S**. (2007) Pathogenic representatives of mycobiota of dry subtropical fruit plants spreed in Absheron. *PhD. dissertation abstract*, Baku, 22 p.

**Aragon F., Oteiza F., Rud J.P.** (2019) Climate change and agriculture: Subsistence farmers' response to extreme heat. URL: www.voxdev.org/topic/agriculture/how-do-farmers-cope-extreme-heat

**Barsukova V.N., Belyakova G.A. et al.** (2005) Small workshop on botany. Algae and fungi. M.: Publishing center "cademy", 240 p.

**Bondartseva M.A.** (1998) The mushrooms determinant of Russia. Order *Aphyllophorales*. Sankt-Peterburg: Science, 740 p.

**Burke M., Emerick K.** (2016) Adaptation to Climate Change: Evidence from US. *Agriculture American Economic Journal: Economic Policy*, **8(3):** 106–140; doi: 10.1257/pol.20130025

**Carraro C.** (2016) Climate change: Scenarios, impacts, policies and development opportunities. *Agricultural Economics*, **47:** 149-157; doi: 10.1111/agec.12306

**Ciais P., Sabine C., Bala G. et al.** (2013) Climate change 2013: The physical science basis. InI M.Tignor, S.K.Allen, J.Boschung, A.Nauels, Y.Xia, V.Bex, & P.M.Midgley (eds.), *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, p. 465–570.

**Crous K.Y.** (2019) Plant responses to climate warming: physiological adjustments and implications for plant functioning in a future, warmer world. *Am. J. Bot*., **106(8):** 1049-1051.

**Crous P., Braun U., Schubert K., Groenewald J.** (2007) The genus *Cladosporium* and similar dematiaceous hyphomycetes. *An institute of the Royal Netherlands Academy of Arts and Sciences*, 252 p.

**Crous P.W., Rossman A.Y., Aime M.C. et al.** (2021) Names of phytopathogenic fungi: A practical guide. *Phytopathology*, **111:** 1500-1508.

**Duarte A.G., Maherali H.** (2022) A meta-analysis of the effects of climate change on the mutualism between plants and arbuscular mycorrhizal fungi. *Ecol. Evol.*, **12(1):** e8518; doi: 10.1002/ece3.8518.

**Dusenge M.E., Duarte A.G., Way D.A.** (2018) Plant carbon metabolism and climate change: Elevated CO2 and temperature impacts on photosynthesis, photorespiration and respiration. *New Phytol.*, 32–49. Doi: 10.1111/nph.15283

**Dugan F.M.** (2017) The identification of fungi: An illustrated introduction with keys, glossary, and guide to literature, 176 p.; doi: 10.1094/9780890545041

**Franks P.J., Adams M.A., Amthor J.S. et al.** (2013) Sensitivity of plants to changing atmospheric $CO_2$ concentration: From the geological past to the next century. *New Phytologist*, **197:** 1077–1094.

**Fang W., Wu J., Cheng M. et al.** (2023) Diagnosis of invasive fungal infections: challenges and recent developments. *J. Biomed. Sci.*, **30:** 42; doi: 10.1186/s12929-023-00926-2

**Gornall J., Betts R., Burke E. et al.** (2010) Implications of climate change for agricultural productivity in the early twenty-first century. *Philos. Trans. R. Soc. Lond. B Biol. Sci.,* 2973-2989.

**Hansen J., Ruedy R., Sato M., Lo K.** (2010) Global surface temperature change. *Reviews of Geophysics*, **48:** RG4004; doi: 10.1029/2010RG000345

**Horst K.R**. (2013) Westcott's plant disease handbook. Eighth Edition. New York: Springer Science, 826 p.

**Monaco P., Baldoni A., Naclerio G. et al.** (2024) Impact of plant-microbe interactions with a focus on poorly investigated urban ecosystems - A review. *Microorganisms,* **12(7):** 1276; doi: 10.3390/microorganisms12071276

**Methods of experimental mycology** (1982) Ed. V.I.Bilay Kyiv: Naukova Dumka, 500 p.

**Nazarov P.A., Baleev D.N., Ivanova M.I. et al.** (2020) Infectious plant diseases: Etiology, current status, problems and prospects in plant protection. *Acta Naturae,* **12(3):** 46-59.

**Samson R.A., Houbraken J., Frisvad J.C.** (2010) Food and indoor fungi. Utrecht: CBS-KNAW, 390 p.

**Sadigov A.N.** (2023) Fruit plants that spread in Azerbaijan. Baku: "Teacher" publishing house, 462 p.

**Stern N.** (2006) The economics of climate change: *The Stern Review*, p. 2-37.

**URL: https://universe84a.com/atlas-of-fungi/**

**Watanabe T.** (2002) Pictorial atlas of soil and seed fungi: Morphologies of cultured fungi and key to species. 2nd Edition, 504 p.

**ORCIDS:**

Konul Bakshaliyeva: https://orcid.org/0000-0002-4876-5542
Gultekin Arabova: https://orcid.org/0009-0005-8689-9321
Sevil Suleymanova: https://orcid.org/0000-0003-3130-443X
Panah Muradov: https://orcid.org/0000-0001-9660-1377

*Journal of Life Sciences & Biomedicine, vol. 6(79), No 2, p. 75-79 (2024)*

# “Year of solidarity for the Green World”: the importance of zoological research for biodiversity conservation in Azerbaijan

**Aladdin Eyvazov**

*Institute of Zoology, Ministry of Science and Education of the Republic of Azerbaijan, 115 A.Abbaszadeh Str., 1128 Pass., 504 Block, AZ1004, Baku, Azerbaijan*

***For correspondence:*** *eyvazov.aladdin@mail.ru*

Received: September 5, 2024; Received in revised form: October 30, 2024; Accepted: December 10, 2024

**In 2024, Azerbaijan declared the "Year of Solidarity for the Green World" to address environmental challenges and promote sustainable development, aligning with global efforts against climate change. The article explores key tasks in modern zoology, focusing on innovative methodologies, such as remote sensing, Geographic Information Systems (GIS), ecological modeling, and citizen science. Recent studies conducted by the Institute of Zoology highlight the application of these modern methods. Research on soil ciliates and the biodiversity in the Kura River basin ciliates showcases the importance of ecological parameters in ecosystem dynamics, and the study of mammals and reptiles once again confirms the importance of the information obtained in the preservation of biodiversity.**

**Research on the reintroduction of large mammals in territories liberated from occupation and Karabakh highlights opportunities for ecological restoration. As a result, these studies demonstrated the commitment of Azerbaijan's zoologists to leverage innovative technologies for biodiversity conservation, addressing the challenges posed by climate change and habitat loss of fauna species while fostering a deeper understanding of the region's rich fauna.**

***Keywords:*** *Azerbaijan, green world, climate change, biodiversity conservation, innovative technologies*

## INTRODUCTION

The "Year of Solidarity for the Green World" was adopted by the Azerbaijan Republic in 2024 through a decree by President Ilham Aliyev as a national initiative to address pressing environmental challenges and promote sustainable development. This initiative aligns with global efforts to combat climate change and protect biodiversity, emphasizing the role of research and innovation in these efforts. In the context of zoological research, the declaration plays a critical role by encouraging the study of Azerbaijan's rich fauna, the effects of climate change on wildlife, and the application of advanced technologies to monitor and conserve the country's unique ecosystems. This synergy between national policy and scientific research aims to safeguard biodiversity, protect ecosystems, and enhance environmental resilience.

## MATERIALS AND METHODS

Existing literature information was used in writing the article. Modern zoological science has an array of critical tasks. These tasks not only focus on understanding and mitigating the impacts of climate change on wildlife but also leverage technological advancements to enhance conservation efforts. This article explores key tasks within modern zoological science, backed by literary sources that highlight recent research and advancements in the field.

## RESULTS AND DISCUSSION

Modern zoology employs a range of innovative methodologies that are essential for

https://doi.org/10.59849/2710-4915.2024.2.75
Available online 31 December 2024

understanding and conserving biodiversity in the face of ongoing environmental challenges. These contemporary techniques not only enhance research capabilities but also provide critical insights for effective conservation strategies. This overview highlights several modern methods, including advancements in genetic technologies, the integration of remote sensing and Geographic Information Systems (GIS), the application of ecological modeling, and the promotion of citizen science initiatives. By leveraging these advanced approaches, zoologists are better equipped to address the pressing issues related to climate change and habitat loss.

Advancements in genetic technologies have significantly transformed conservation efforts within modern zoology. Conservation genetics has become a crucial tool for understanding genetic diversity within and between populations, which is essential for ensuring species' resilience to environmental changes (Frankham, 2010). Techniques such as DNA barcoding and genome sequencing are now widely employed to assess genetic diversity and inform effective conservation strategies (Hebert et al., 2003).

The integration of remote sensing and Geographic Information Systems (GIS) has also become indispensable in contemporary zoological research. These technologies facilitate large-scale data collection, allowing scientists to monitor habitat changes and model species distributions under various climate scenarios (Turner et al., 2003; Pettorelli et al., 2005). By utilizing these tools, researchers can gain valuable insights into how environmental changes impact wildlife.

Ecological modeling and simulation represent another cutting-edge methodology in modern zoology. These approaches help elucidate complex ecological processes and predict future scenarios by simulating the impacts of climate change on ecosystems and species interactions (Urban et al., 2016). Such predictive modeling is crucial for conservation planning and prioritizing efforts to protect vulnerable species.

Furthermore, promoting citizen science initiatives has emerged as a vital strategy in modern zoology. Engaging the public in data collection not only enhances research efforts but also raises awareness about conservation issues, fostering a deeper connection between communities and nature (Silvertown, 2009; Bonney et al., 2009). Citizen science empowers individuals to contribute to biodiversity monitoring and conservation, creating a sense of ownership over local ecosystems.

The analysis of recent publications by the employees of the Institute of Zoology highlights a broad spectrum of scientific research utilizing advanced methodologies in various fields of biology and ecology. A key area of focus has been the role of trophic factors in the microzonal distribution of soil ciliates, as explored by I.Alekperov. His study emphasizes the influence of food availability and ecological parameters on the distribution of these organisms across different microzones, offering critical insights into ecosystem dynamics and soil community structures (Alekperov, 2021).

Building on this, I.Alekperov, together with E.Tahirova, has conducted an extensive examination of the biodiversity of free-living ciliates in the Kura River basin. By employing modern classification techniques and detailed morphological analysis, they assess the biological diversity of these microorganisms and underscore their ecological significance within river ecosystems, further expanding the understanding of freshwater biodiversity (Алекперов, Тагирова, 2020).

In parallel, Morhun et al. have made significant strides using molecular markers and scanning electron microscopy (SEM) to uncover pseudocryptic diversity in the amphipod species *Dikerogammarus bispinosus*. Their work reveals previously hidden species diversity, which holds important implications for managing biological invasions in the Ponto-Caspian ecosystems. This kind of research is vital for informing strategies to control invasive species that threaten ecological balance (Morhun et al., 2022).

In Azerbaijan, the work carried out in the field of increasing rare and endangered species and their reintroduction to the areas where they were historically inhabited is of great importance. For example, based on international experience, was launched in order to achieve restoration of gazelles in new areas by releasing them to their historical areasthe project "Protection, reintroduction and restoration of historical areas of gazelles in the territory of the Republic of

Azerbaijan". The project started in 2010 is being implemented by the Ministry of Ecology and Natural Resources with the support of the Heydar Aliyev Foundation, IDEA Public Union and WWF Azerbaijan Representation.

Conservation efforts of carnivorous mammals in the South Caucasus are also well represented in the work of E.Askerov and colleagues. In a pivotal study from 2015, they provided the first evidence of the leopard (Panthera pardus) reoccupying its historic range in the region, using field data to confirm this critical biodiversity event (Askerov et al., 2015). This finding was later expanded upon in 2018 when E.Askerov et al. emphasized the importance of the southeastern Lesser Caucasus as a crucial landscape for leopard conservation. They outlined key conservation strategies and highlighted the necessity of cross-border cooperation to ensure the survival of this iconic species (Askerov et al., 2018).

Another essential contribution to biodiversity research comes from N.Snegovaya et al., who employed genetic data to develop a molecular phylogeny of the dragonfly family *Aeshnidae*, with particular attention to species in the Western Palearctic. This study not only refines species classification but also contributes to a deeper understanding of their evolutionary history and biogeographical patterns, showcasing how genetic tools can illuminate species' past and present dynamics (Schneider et al., 2023).

Shifting the focus to the post-conflict region of Karabakh, A.Eyvazov's research examines the potential for reintroducing large mammals to the liberated territories. His work assesses the current state of fauna in the region and explores the opportunities for restoring populations of endangered species, reflecting the growing interest in post-war ecological restoration (Eyvazov, 2021). Complementary to this, a study by A.Eyvazov, T.Iskenderov, and G.Gasimova investigates the reptiles inhabiting the same region. The detailed description of these species not only contributes to understanding the biodiversity of the area but also highlights the ecological significance of their habitats (Eyvazov et al., 2022).

F.Rzayev and his colleagues have also made notable advancements in understanding environmental health, focusing on the bioaccumulation of aluminum nanoparticles in simplified aquatic food chains. Through microscopic methods, their research assesses the impact of these nanoparticles on different trophic levels, offering crucial insights into the potential ecological consequences of nanoparticle contamination in aquatic ecosystems (Rzayev et al., 2021).

In addition to these studies, E. Yusifov and E. Ahmadov (2021) summarized the results of the studies conducted at the Institute of Zoology and it was emphasized that the fauna of Azerbaijan includes over 40,000 species.

Their work notes that the ornitofauna comprises 405 species from 19 families, many of which are included in the IUCN Red List. The fish fauna consists of 99 taxa, while mammals, reptiles, and arachnids include 115 species, 63 species, and 1,837 species, respectively. Class Insecta is represented by over 10,000 species (Yusifov and Ahmadov, 2021).

For the first time, the categories and criteria used in the compilation of the IUCN Red List were taken as the basis for determining the statuses of the species included in the III edition of the "Red Book" (2023). In this book, species have been assessed using the IUCN Red List categories and criteria, version 3.1 before applying the IUCN Guidelines for Application of IUCN Red List Criteria at Regional and National Levels.

As a result of an assessment according to IUCN categories and criteria, 7 species of aquatic invertebrates, 82 species of insects, 11 species of fish, 6 species of amphibians, 18 species of reptiles, 78 species of birds, 39 species of mammals are included in the III edition of the Red Book, published in 2023. The number of species included in the pink list, compiled for the first time, is 41 (Red Book of the Republic of Azerbaijan. Fauna, 2023).

As a result of multi-year research conducted in the Institute of Zoology in recent years, now fauna includes more than 2000 species of free-living and parasitic protozoa, more than 2000 species of helminths that parasitize humans and animals, more than 400 species of phytohelminths, up to 290 species of rotators, more than 360 species of crustaceans, more than

14,000 species of insects, More than 1200 species of arachnids, more than 1100 species of ticks, more than 181 species of mollusks, and the vertebrate animal kingdom is represented by 701 species, including 1 cyclostomi, 104 fish, 11 amphibians, 63 reptiles, 407 birds, and 115 mammals (Taxonomic spectrum of Azerbaijani fauna (*Protozoa* and *Helminths*), 2022; Information system of Azerbaijani fauna (*Vertebrates*), 2023).

Together, these studies underscore the Institute of Zoology's commitment to applying a variety of methodological approaches-molecular markers and scanning electron microscopy to in-depth ecological analyses to address pressing problems in biodiversity and ecosystem research. This body of work not only advances scientific knowledge but also provides practical insights for conservation and environmental management efforts in Azerbaijan and beyond.

## CONCLUSION

The adoption of the "Year of Solidarity for the Green World" by Azerbaijan highlights the critical intersection of national policy and scientific research in addressing environmental challenges. By leveraging innovative methodologies and technologies, the zoological community is well-equipped to tackle the impacts of climate change and habitat loss, ensuring the preservation of biodiversity and ecosystems in Azerbaijan. This commitment to advancing research and conservation efforts will contribute significantly to understanding and protecting the region's rich fauna, ultimately fostering a more sustainable future.

## REFERENCES

**Information system of Azerbaijani fauna (*Vertebrates*)** (2023) Baku: Taraggi Publ. House, 598 p. **(in Azerbaijan).**

**Taxonomic spectrum of Azerbaijani fauna (*Protozoa* and *Helminths*)** (2022) Taraggi Publ. House, 141 p. **(in Azerbaijan).**

**Alekperov I.K.** (2021) The role of trophic factor in microzonal distribution of soil ciliates. *International Journal of Advanced Psychiatric Nursing*, **1(1):** 01-04.

**Alekperov I.K., Tahirova E.N. (2020)**. Biodiversity of free-living ciliates of the Kura River basin (within Azerbaijan). *Experimental Biology and Biotechnology*, **3:** 97-113 (in Russian).

**Askerov E., Talibov T., Manvelyan K., Zazanashvili N., Malkhasyan A., Fatullayev P., Heidelberg A.** (2015) South-Eastern Lesser Caucasus: the most important landscape for conserving the Leopard (*Panthera pardus*) in the Caucasus region (*Mammalia: Felidae*). *Zoology in the Middle East*, **61(2):** 95–101; https://doi.org/10.1080/09397140.2015.1035003

**Askerov E., Talibov T., Manvelyan K., Zazanashvili N., Fatullayev P., Malkhasyan A.** (2018) Leopard (*Panthera pardus*) reoccupying its historic range in the South Caucasus: a first evidence (*Mammalia: Felidae*). *Zoology in the Middle East*, **65(1):** 88–90; https://doi.org/10.1080/09397140.2018.1552349

**Bonney R., Cooper C. B., Dickinson J., Kelling S., Phillips T., Rosenberg K.V., Shirk J.** (2009) Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *BioScience*, **59(11):** 977-984.

**Eyvazov A.** (2021) Fauna of Karabakh and liberated territories and prospects of reintroduction of some largest mammals. *Journal of Life Sciences & Biomedicine*, **3(76), (2):** 33-40.

**Eyvazov A., Iskenderov T., Gasimova G.** (2022) About the reptiles of the Karabakh territories liberated from occupation and their habitats. *Journal of Life Sciences & Biomedicine*, **4(77), (2):** 23-28.

**Frankham R.** (2010) Challenges and opportunities of genetic approaches to biological conservation. *Biological Conservation*, **143(9):** 1919-1927.

**Hebert P.D.N., Ratnasingham S., de Waard J. R.** (2003) Barcoding animal life: cytochrome c oxidase subunit 1 divergences among closely related species. *Proceedings of the Royal Society of London, Series B: Biological Sciences*, **270(Suppl 1):** S96-S99.

**Morhun H., Copilas-Ciocianu D., Rewicz T., Son M.O., Khomenko A., Huseynov M., Utevsky S., Grabowski M.** (2022) Molecular markers and SEM imaging reveal pseudocryptic

diversity within the Ponto-Caspian low-profile amphipod invader *Dikerogammarus bispinosus*. *The European Zoological Journal*, p. 87–101.

**Parmesan C.** (2006) Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology, Evolution, and Systematics*, **37:** 637-669.

**Pettorelli N., Vik J. O., Mysterud A., Gaillard J. M., Tucker, C. J., Stenseth N.C.** (2005) Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends in Ecology & Evolution*, **20(9):** 503-510.

**Red Book of the Republic of Azerbaijan. Fauna.** (2023) Third edition. 279 p.

**Rzayev F., Gasimov E., Agayeva N.J., Manafov A.A., Mamedov C.A., Ahmadov I.S., Khusro A., Valan Arasu M., Sahibzada M.U.K., Al-Dhabi N.A., Choi K.C.** (2022) Microscopic characterization of bioaccumulated aluminium nanoparticles in simplified food chain of aquatic ecosystem. *Journal of King Saud University – Science*, **34(1):** 101666; doi: 10.1016/j.jksus.2021.101666

**Schneider T., Vierstraete A., Kosterin O., Ikemeyer D., Fang-Shuo H., Snegovaya N., Dumont H.J.** (2023) Molecular phylogeny of holarctic Aeshnidae with a focus on the West Palaearctic and some remarks on its genera worldwide (*Aeshnidae, Odonata*), *Diversity*, **15(9):** 950; https://doi.org/10.3390/d15090950

**Silvertown J.** (2009) A new dawn for citizen science. *Trends in Ecology & Evolution*, **24(9):** 467-471.

**Turner W., Spector S., Gardiner N., Fladeland M., Sterling E., Steininger M.** (2003). Remote sensing for biodiversity science and conservation. *Trends in Ecology & Evolution*, **18(6):** 306-314.

**Urban M.C., Bocedi G., Hendry A.P., Mihoub J.-B., Pe'er G., Singer A., Bridle J.R., Crozier L.G., De Meester L., Godsoe W., Gonzalez A., Jennions M.D., Krug C.B., Morelli T.L., Norberg J., Palstra F.P., Phillips B.L., Schmitz A., Sih A., Travis J.M.J**. (2016) Improving the forecast for biodiversity under climate change. *Science*, **353(6304):** aad8466; doi: 10.1126/science.aad8466.

**Walther G.-R., Post E., Convey P., Menzel A., Parmesan C., Beebee T.J.C., Fromentin, J.-M., Hoegh-Guldberg, O., Bairlein, F.** (2002) Ecological responses to recent climate change. *Nature*, **416(6879):** 389-395.

**Yusifov E., Ahmadov E.** (2021) Fanual diversity of Azerbaijan. *Biodiversity, conservation and sustainability in Asia*. *M.Öztürk, V.Altay, R.Efe (Editors).* **Vol. 1 (Chapter 19):** Prospects and Challenges in West Asia and Caucasus. 659 p.

**ORCID:**
Aladdin Eyvazov: https://orcid.org/0000-0002-8112-6478

*Journal of Life Sciences & Biomedicine, vol. 6(79), No 2, p. 80-86 (2024)*

# Combined effect of TYLCV infection and drought mitigates stress in tomato (*Solanum lycopersicum* L.) through the modulation of antioxidant enzymes

**Samra Mirzayeva**

*Institute of Molecular Biology & Biotechnologies, Ministry of Science and Education of the Republic of Azerbaijan, 11 Izzat Nabiyev Str., AZ1073, Baku, Azerbaijan,*

***For correspondence:*** *samrayusifova@yahoo.com*

Received: September 25, 2024; Received in revised form: November 12, 2024; Accepted: December 19, 2024

**Plant viruses cause considerable losses in agricultural crops globally, reducing the yield and quality of agricultural goods. We conducted the study of antioxidant enzymes (APO, BPO) in a local Azerbaijani genotype (Shalala) subjected to combined effects of drought and TYLCV stresses. Virus inoculation provided by *Bemisia tabaci* – whitefly insects that feed on them, in a controlled environment. According to our results, high enhancements in APO and BPO activity occurred only under drought and only in TYLC-infected tomato samples. As a result, we found that the Shalala genotype had higher levels of APO and BPO, although these levels were very low and barely different from the control ones.**

***Keywords:*** *Solanum lycopersicum* L.*, drought, tomato yellow leaf curl virus, Bemisia tabaci, combined stress, ascorbate-peroxidase, benzidine peroxidase*

## INTRODUCTION

Environmental stress can cause plants to change the way they use their resources like physical and chemical qualities (Agrell et al., 2005; Cui et al., 2012). Priming defense, being a physiological process, makes plants get ready to respond faster or more strongly to climate change and biotic stress (Frost et al., 2008). This process greatly changes how insects and plants interact when they are dealing with environmental stress, disease, and insect infestations (Sun et al. 2013, 2017). Viral infection, alongside abiotic stress, can also affect the way whiteflies, viruses and plants interact. Begomoviruses are the most detrimental group of plant viruses in warm places, are often accompanied by outbreaks of whiteflies, particularly tomato yellow leaf curl virus, which is one of the most destructive begomoviruses and has global distribution (Bilgin et al., 2008; Guo et al., 2017). Sun et al. (2017) found that TYLCV makes the Mediterranean (MED) whitefly stronger by hindering its JA defense pathway. The whitefly, *Bemisia tabaci Gennadius* (*Hemiptera: Aleyrodidae*), is a type of bug that can cause a lot of damage to plants. It sucks the sap from the plants and can also spread viruses to them. It can be found worldwide and is a massive problem for farmers (Stansley and Naranjo 2010). Bemisia tabaci MED has recently spread in China causing huge damage to crops by feeding on them and spreading TYLCV (Chu et al., 2010; Rao et al., 2011; Cui et al 2018; 2019).

Diseases caused by viruses harm tomatoes and cause big losses in production around the world just like various biotic stress. Whiteflies spread a kind of virus called geminiviruses (genus: *Begomovirus*) that affects tomato plants. This virus is a big problem for growing tomatoes in hot and humid areas. These viruses make plants sick in different ways. One disease they cause is called tomato yellow leaf curl disease (TYLCD), which damages tomato plants (Prasanna et al., 2015). Tomato yellow leaf curl is a harmful virus that affects tomatoes. In countries with tropical and subtropical climates, tomato crops have been



https://doi.org/10.59849/2710-4915.2024.2.80
Available online 31 December 2024

damaged a lot. TYLCV is common and can be found in many places where tomatoes are cultivated. (Michael et al., 2009; Navas-Castillo et al. 2011; Chen et al., 2016). When plants get a virus, their chemical composition changes to a great extent causing a decrease in quality and quantity of the crops. Different reports say that when a virus multiplies in a plant cell, it changes the plant's chemical composition and disrupts the physiological processes like photosynthesis, transpiration and respiration of the infected plants which affect the growth and yield (Tajul et al., 2011; El-Dougdoug et al., 2014b). This can cause the infected plants not to grow well and not produce as much. Furthermore, it has been reported that figuring out what makes up cells in virus-infected plants is really important for understanding what the host cells are doing and how much damage the virus has caused. A viral infection makes cells leakier, causing them to lose water. This also tells us why the infected leaves have a cup shape, especially when the symptoms are very bad (Oleinikova et al., 1969).

According to Moshe et al., (2012), responsive oxygen species (ROS) rummaging components in plants include proteins such as superoxide dismutase (Grass), ascorbate peroxidase (APX), glutathione peroxidase (GPX), and catalase (CAT). SODs act as the primary line of defense against ROS, dismutating superoxide to $H_2O_2$. APX, GPX, and CAT along these lines detoxify $H_2O_2$. Most anti-oxidative proteins were recognized in TYLCV-infected tomatoes. SODS, APX, thioredoxin peroxidase, ferredoxin-nitrite reductase were more abundant in susceptible than in resistant plants. Plant thioredoxins are the key factors in oxidative stress response. TYLCV immunization enhances the defense chemicals of tomato such as peroxidase, polyphenol oxidase (PPO) and phenylalanine ammonia-lyase. TYLCV increases the exercises of defense proteins and diminishes disease index considerably so as to extend tomato resistance to TYLCV (Li et al., 2012; Sofy et al., 2014, 2017).

## MATERIALS AND METHODS

**Plant material and stress treatment:** We used the Shalala genotype from Azerbaijan to study how tomato plants (*Solanum lycopersicum*) respond to both virus and drought stresses. The Shalala seeds came from the Ministry of Agriculture, Horticultural Research Institute of Azerbaijan Republic. Seeds were planted in a special room without insects at a temperature of $26/20^0$C during the day and night. They were exposed to 16 hours of light and 8 hours of darkness each day, air humidity being 60-70%. After 2-3 weeks, young tomato plants were moved to 2-litre pots. The plants were split into four groups: healthy-H plants (control variant), virus-inoculated plants (V), drought-affected plants (D), and plants affected by both virus and drought (VD). The main highlight lies in the research conducted with 15 tomato plants in each group, a total of 180 tomato plants. The work had been conducted in 3 biological replicates. While conducting the research, we moved whiteflies (*Bemisia tabaci*) from virus-infected tomato plants to healthy tomato plants. Tomato plants were put in boxes made of a special material called polycarbonate that stops insects from getting in. Around 25 whiteflies were put on each tomato plant to feed. 3-4 weeks later, the experimental plants demonstrated signs of TYLCV.

**DNA extraction and polymerase chain reaction (PCR):** Using the CTAB method, these plants provided leaf samples and total DNA was extracted from them (Aboul-Maaty et al., 2019). Nano Drop1000 (Thermo Scientific) was utilized to analyze DNA concentration and purity spectrophotometrically. Later, using special primers MA13/MA26 (5'-AATGCAATCTTCGT CACC-3'/5'-CGCCCGTCTCGAAGGTTCG-3'), additional duplicates of the DNA samples were created for TYLCV detection. PCR reaction in 25 µl volume: 1X Taq Buffer; 2 mM MgCl2; 0.15 mM dNTP mix; 0.2 µm forward and reverse primer; 1.24 U Taq DNA polymerase; and collected with 100 ng of DNA. PCR: pre-denaturation at 95 °C for 1 min. 35 cycles (denaturation at 95 °C for 30 s, annealing at 65 °C for 1 min and elongation at 72 °C for 1 min) and a final elongation at 72°C for 10 min were performed. PCR response items were visualized on a 1% TBE agarose gel utilizing ethidium bromide in a gel documentation gadget (Uvitek, Britain). PCR analysis showed that a piece of DNA about 1.2 kilobases long was synthesized.

Virus-infected tomato samples were separated into two groups to test the way they handle dry conditions: one group had only drought (D), and the other had TYLCV/drought. There was a 25-day period of drought. On the 10th, 17th, and 24th days of the experiment, the plants were given about ~50 ml of water to avoid dying completely.

**Isolation of the enzyme extract:** Total cell extract was obtained by homogenizing tomato leaves in a medium containing 1 mM EDTA (pH 8.0), 2 mM phenylmethylsulfonyl fluoride (PMSF), 1% PVP, 100 mM Na phosphate buffer (pH 7.8), 0.1% Triton X-100, 2 mM ascorbate. Furthermore, samples were filtered, and centrifuged for 20 min at 15,000×g. The supernatant remaining after the process was used to study peroxidase enzymes.

**Activity of peroxidases:** The activities of the studied enzymes in leaves of tomato were assessed spectrophotometrically (Ultrospec 3300 PRO, Amersham, USA) at a linear reaction. Three different samples for each treatment were taken and analyzed twice.

**Ascorbate peroxidase** (APO, EC 1.11.1.11) activity was measured using a modified version of Nakano and Nakano and Asada's (1981) technique. The technique is based on measuring the rate at which ascorbate breaks down hydrogen peroxide to produce water and dehydroascorbate. At 290 nm, optical density was measured in a spectrophotometer. The activity was determined using a molar extinction coefficient of $\varepsilon$=2.8 $mM^{-1}$ $cm^{-1}$ and expressed in µmol(ascorbate) $mg^{-1}$ (protein) $min^{-1}$.

The increase in optical density of the reaction mixture for one minute at 590 nm was used to test the **activity of the benzidine-type peroxidase** (BPO EC 1.11.1.7.) (Gechev et al., 2002). By taking into account the extinction coefficient, $\varepsilon$=39 $mM^{-1}$ $cm^{-1}$, the activity was estimated in µmol (benzidine product) $mg^{-1}$ (protein) $min^{-1}$.

**Statistical analysis:** The unequal variance two-tailed Student's t-test was utilized to examine the significance of variations between the control and experimental groups. P-values less than 0.05 were regarded as statistically significant data. For every treatment, three distinct samples were obtained and subjected to two analyses.

## RESULTS AND DISCUSSION

Comparing the leaves of the uninfected control plants to the infected leaf samples, a significant rise in the activities of APO, and BPO was discovered. Every stressed plant manifested a high level of peroxidase activity. Samples from groups V and D exhibited higher BPO and GPO activity, while samples from groups VD showed less activity than V and D groups of plants (Figure 3, 4). Therefore, APO and BPO activity were respectively in control tomatoes 47 and 17 (µmol $H_2O_2$/mg·protein·min), Virus infected samples 66 and 23 (µmol $H_2O_2$/mg·protein·min), drought-treated plants 70 and 22 (µmol $H_2O_2$/mg·protein·min) and dual stress applied tomatoes 50 and 19 (µmol $H_2O_2$/mg·protein·min). The current study found that certain viral infections cause significant alterations in the components of plants' antioxidant defense systems.

**A** **B** **C** **D**

**Fig. 1.** The tomato plant grown under artificial climatic conditions (8/16 photoperiod, 26/20±1°C temperature, 60–70 % relative humidity): control (A), TYLCV infected (B), drought treatment (C), combined stress (D).

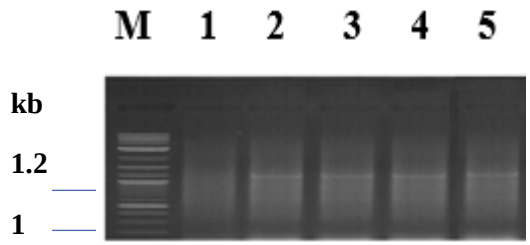


**Fig. 2.** M-100 bp DNA ladder, 1-negative control; 2; 3; 4, 5 TYLCV infected tomato samples (Shalala).

Tomatoes (*Solanum lycopersicum L.*) are widely cultivated and highly popular vegetables worldwide. Many individuals worldwide enjoy consuming tomatoes because of their delicious flavor and numerous health benefits (Alhudiab et al., 2014; Chen et al., 2016). TYLCV is responsible for causing harm to tomato plants through the development of the tomato yellow leaf curl disease (Michael et al., 2009; EL-Dougdoug et al., 2013). This disease, as noted by Lefeuvre et al., (2010) and Deng et al., (2015) is one of the most pernicious in the world. TYLCV-EGS and TYLCV-EGT isolates may both cause symptoms when physically injected into healthy plants using a syringe and then spread by whiteflies (Mirzayeva et al., 2023). Additionally, it has been stated that understanding the cellular components of a virus-infected plant is crucial to comprehending the host cell's actions as well as the type and degree of harm the virus has produced. According to the results of the current investigation, infected tomato plants with TYLCV-EGS and TYLCV-EGT had altered metabolic and biochemical parameters when compared to healthy controls across four distinct tomato cultivars.

Hu et al., (2007) reported an increase in sodium content synchronized with an increase in drought stress in their research on *Purslane* (*Portulaca oleracea* L.) leaves. When examining the effect of drought stress on the ionic contents in soybean shoots, Niakan and Ghorbanli (2007) found out that sodium level increased by stress relative to blank level, but potassium concentration decreased. They state that the decrease in water potential, which in turn led to a decrease in the plant's ability to transfer potassium from the root to the shoot, is the source of the shoot's decreased potassium concentration. An increase in sodium levels in stressed plants is a defense mechanism that helps the plants regulate cell osmotic pressure and soil solute uptake of water and nutrients.

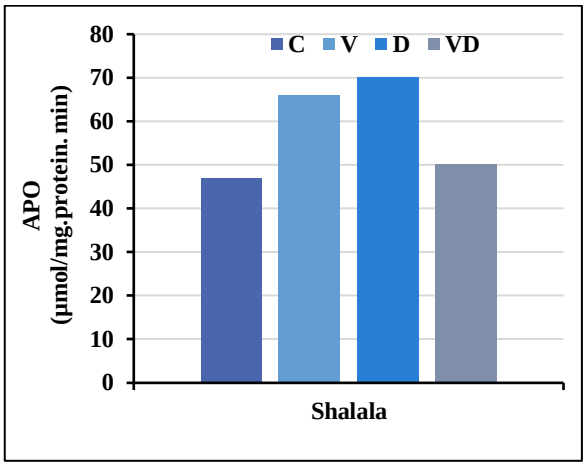


**Fig. 3.** Ascorbate peroxidase (APO) activity in stressed Shalala genotype (µmol/mg·protein·min**)**: C-control plants, V-TYLCV infected tomatoes, D-drought treatment, VD-virus and drought applied samples (combined stress).

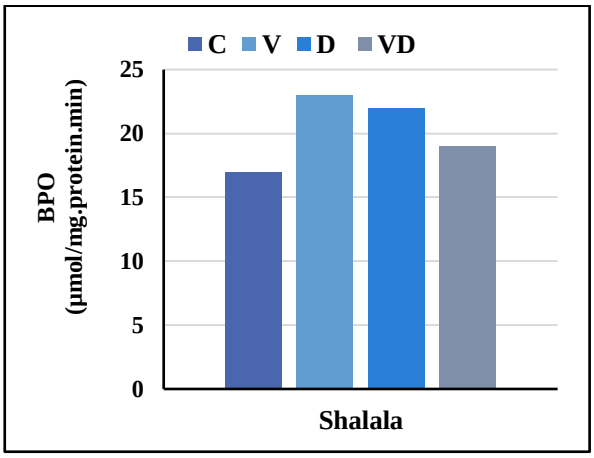


**Fig. 4.** Benzidine peroxidase (BPO) activity in stressed Shalala genotype (µmol/mg·protein·min): C-control plants, V-TYLCV infected tomatoes, D-drought treatment, VD-virus and drought applied samples (combined stress).

In another study, proline content enhanced in tobacco mosaic virus (TMV)-infected pepper (*Capsicum annuum* L.) plants compared to corresponding controls (Sercan, 2013; Pazarlar et

al., 2013). In order to successfully block off the pathogen and stop the disease process, plants that are exposed to microbial pathogens release reactive oxygen species (ROS) that cause the plant cells surrounding the infection site to undergo programmed cell death (Apel and Hirt, 2004; Moshe et al., 2012). One of the most important effects of different stresses is the creation of oxidative stress, which develops under high levels of reactive oxygen species (ROS) in cells subjected to stress (Kumar et al., 2010). Plants develop complex antioxidant metabolism to improve the damage caused by ROS. The creation of lignin and other oxidative phenols that amplify the cell structure when attacked by pathogens are catalyzed by PPO and POD enzymes (Deng et al., 2015). Studies report that TYLCV-infected tomato plants had higher levels of antioxidants like BPO, PPO, APO, and CAT compared to healthy plants. This was true for all the different groups of tomato plants we involved in experiments. The acquired results happened to overlap with the research done by Sudhakar et al. (2006), Rai et al. (2011), Jaiswal et al. (2012), Huseynova and Aliyev (2012) and Sofy et al. (2013). According to these publications, activities of leaf antioxidant enzymes saw an increase when affected by biotic stress.

In all the plants tested, both amylase and protease enzymes led to a significant increase in TYLCV-infected samples (Sofy et al., 2017). TYLCV-EGT isolate demonstrated the most essential impact on both antioxidant and hydrolytic enzyme activities out of the two types of TYLCV isolates. Antioxidant enzymes are activated as a result of the stress in infected tomato cultivars. Plants have evolved advanced antioxidant systems to shield cellular membranes and organelles from the destructive effects of ROS (Šubr et al., 2006; Sofy et al., 2014). Viral infection causes an increase in peroxidase activity, which was observed in peaches, apricots (Diaz-Vivancos et al., 2006; Radwan et al., 2010).

Peroxides appeared to be pivotal pathogenesis-related proteins (PR-proteins) in the works of Almagro et al. (2009) and Sofy et al. (2014). They play a crucial role in defending plants against pathogens, by participating in the deletion process of hydrogen peroxide from the cells. Thus, the timing and location of higher levels of guaiacol peroxidase (GPX) and ascorbate peroxidase (APX) activity, and their role in the stiffening of cell walls, show that peroxidases help create substances that block pathogen penetration. It was reported that infected plant parts had higher levels of SOD, CAT, APO, and BPO activities and hydrogen peroxide when they were infected with a virus. An increase in viral infection prompted the heightened activity of SOD, CAT, GPX, and APX, demonstrating their roles in eliminating harmful substances from ROS.

## REFERENCES

**Aboul-Maaty N., Oraby H.** (2019) Extraction of high-quality genomic DNA from different plant orders applying a modified CTAB-based method. *Bulletin of the National Research Centre*, **43:**25-35.

**Agrell J., Kopper B., McDonald E.P., Lindroth R.L.** (2005) $CO_2$ and $O_3$ effects on host plant preferences of the forest tent caterpillar (*Malacosoma disstria*). *Global Change Biol.*, **11:** 588–599.

**Alhudiab K., Alaraby W., Rezk W.** (2014) Molecular characterization of tomato yellow leaf curl disease associated viruses in Saudi Arabia. *International Journal of Virology*, **10:** 192-203.

**Almagro L., Gomez Ros L.V., Belchi-Navarro S., Bru R., Ros Barcelo A., Pedreno M.A.** (2009) Class III peroxidases in plant defense reactions. *J. Exp. Bot.*, **60:** 377–390.

**Apel K., Hirt H.** (2004) Reactive oxygenspecies: metabolism, oxidative stress and signal transduction. *Plant Biology*, **55:** 373-399.

**Bilgin D.D., Aldea M., O'Neill B.F., Benitez M., Li M., Clough S.J., DeLucia E.H.** (2008) Elevated ozone alters soybean-virus interaction. *Mol. Plant Microbe Interact*, **21:** 1297–1308.

**Chen H., Lin C., Tsai W., Kenyon L., Chan M., Yen J., Chang S., Peña R., Schafleitner R.** (2016) Resistance to viral yellow leaf curl in tomato through RNAi targeting two Begomovirus species strains. *J. Plant Biochem. Biotechnol.*, **25:** 199–207.

**Chu D., Wan F.H., Zhang Y.J., Brown J.K.** (2010) Change in the biotype composition of *Bemisia tabaci* in Shandong Province of China

from 2005 to 2008. *Environ. Entomol.*, **39:** 1028-1036.

**Cui F., Wu H., Safronov O., Zhang P., Kumar R., Kollist H., Salojärvi J., Panstruga R., Overmyer K.** (2018) *Arabidopsis* $MLO_2$ is a negative regulator of sensitivity to extracellular reactive oxygen species. *Plant Cell Environ.*, **41:** 782–796.

**Cui H., Sun Y., Zhao Z., Zhang Y.** (2019) The combined effect of elevated $o_3$ levels and TYLCV infection increases the fitness of *Bemisia tabaci* Mediterranean on tomato plants. *Environmental Entomology*, **48:** 1425–1433.

**Cui H.Y., Sun Y.C., Su J.W., Ren Q., Li C.Y., Ge F.** (2012) Elevated $O_3$ reduces the fitness of *Bemisia tabaci* via enhancement of the SA-dependent defense of the tomato plant. *Arthropod-Plant Int.*, **6:** 425–437.

**Deng Y., He S., Geng Q., Duan Y., Guo M., Li J., Cao Y.** (2015) Synthesis and biological activity evaluation of novel amino acid derivatives as potential elicitors against Tomato yellow leaf curl virus. *Amino Acids,* **47:** 2495–2503.

**Diaz-Pendon J.A., Canizares M.C., Moriones E., Bejarano E.R., Czosnek H., Castillo J.N.** (2010) Tomato yellow leaf curl viruses: Ménage a troi between the virus complex, the plant and the whitefly vector. *Molecular Plant Pathology,* **11:** 441–450.

**El-Dougdoug N.K., Mahfouze S.A., Ahmed S.A., Othman B.A., Hazaa M.M.** (2014) Characterization, nucleotide sequencing of tomato yellow leaf curl virus Egyptian isolate. Sci. *Agri.,* **7:** 58-69.

**Frost C.J., Mescher M.C., Carlson J.E., De Moraes C.M.** (2008) Plant defense priming against herbivores: getting ready for a different battle. *Plant Physiol.,* **146:** 818–824.

**Gechev T., Gadjiev I., van Breusagem E. et al.** (2002) Hydrogen peroxide protects tobacco from oxidative stress by inducing a set of antioxidant enzymes. *Cell Mol. Life Sci.,* **59:** 708-714

**Guo H.G., Wan S.F., Ge F.** (2017) Effect of elevated $CO_2$ and $O_3$ on phytohormone-mediated plant resistance to vector insects and insect-borne plant viruses. *Sci. China Life Sci.*, **60:** 816–825.

**Hu Y.B., Tucher S.Z., Schmidhalter U.** (2007) Short-term effects of drought and salinity on mineral nutrient distribution along growing leaves of maize seedlings. *En. and Exper. Botany*, **60:** 268-275.

**Huseynova I., Aliyev J.** (2012) Evaluation of free radicals and antioxidant properties of virus infected food crops in Azerbaijan. *J. of Life Sci.*, **6:** 1307-1316.

**Jaiswal N., Singh M., Dubey R.S., Venkataramanappa V.D., Datta D.** (2013) Phytochemicals and antioxidative enzymes defence mechanism on occurrence of yellow vein mosaic disease of pumpkin (*Cucurbita moschata*). *Biotech,* **3:** 287–295.

**Kumar A., Mali P.C., Manga V.K.** (2010) Changes of some phenolic compounds and enzyme activities on infected pearl millet caused by *Sclerospora graminicola. Inter. J. Plant Physiol. Biochem.*, **2:** 6–10.

**Lefeuvre P., Martin D.P., Harkins G., Lemey P., Gray A.J.A., Meredith S., Lakay F., Monjane A., Lett J.M., Varsani A., Heydarnejad J.** (2010) The spread of Tomato yellow leaf curl virus from the Middle East to the world. *PLoS Pathog*, **6:** e1001164.

**Li Y., Shi rong G., Jun Y., Wei-min Z.** (2012) Effects of BTH on TYLCV resistance, photosynthetic characteristics and related defense enzymes of tomato seedlings. *Journal of Nanjing Agric.Univ*. **6:** 1-10.

**Michael J.M., Ogata D.Y., Fukuda S.K., Shimabuku R., Borth W.B., Sether D.M., Hu J.S.** (2009*)* The Global Dimension of Tomato Yellow Leaf Curl Disease: Current Status and Breeding Perspectives. *Tomato Yellow Leaf Curl,* **1:**70**.**

**Mirzayeva S., Huseynova I., Özmen C.Y., Ergül A.** (2023) Physiology and gene expression analysis of tomato (*Solanum lycopersicum* L.) exposed to combined-virus and drought stresses. *Plant Pathol. J.*, **39:** 466-485.

**Moshe A., Jens P., Brotman Y., Mikhail K., Iris S., Henryk. C., Rena. L.G.** (2012) Stress responses to Tomato yellow leaf curl virus (TYLCV) infection of resistant and susceptible tomato plants are different. *Metabolomics,* **1:** 1-13.

**Nakano Y., Asada K.** (1981) Hydrogen peroxide is scavenged by ascorbate-specific peroxidase in spinach chloroplasts. *Plant Cell. Physiol.,* **22:**

867-880,

**Navas-Castillo J., Fiallo-Olivé E., Sánchez-Campos S.** (2011) Emerging virus diseases transmitted by whiteflies. *Annu. Rev. Phytopathol.,* **49:** 219– 248.

**Niakan M., Ghorbanli M.** (2007) The effect of drought stress on growth parameters, photosynthetic factors, content of protein, Na and K in shoot and root in two Soybean cultivars. *Iranian. Biol. J.,* **8:** 17-33.

**Oleinikova T.V.** (1969) The effect of drought on protoplasm permeability in cells of spring wheat leaves. Byull. Vses. *Inst. Rasteniev.,* **14:** 25–30.

**Pazarlar S., Gumus M., Öztekin G.B.** (2013) The Effects of Tobacco mosaic virus Infection on Growth and Physiological Parameters in Some Pepper Varieties (*Capsicum annuum* L.). *Not Bot. Horti. Agrobo.,* **41:** 427-433.

**Prasanna H.C., Kashyap S.P., Krishna R., Sinha D.P., Reddy S., Malathi V.G.** (2015) Marker assisted selection of Ty-2 and Ty-3 carrying tomato lines and their implications in breeding tomato leaf curl disease resistant hybrids. *Euphytica,* **204:** 407–418.

**Radwan D.E.M., Fayez A.K., Mahmoud Y.S., Lu G.** (2010) Modifications in antioxidant activity and protein composition of bean leaf due to bean yellow mosaic virus infection and SA treatments. *Acta Physiologae Plantarum*, **32:** 315-324.

**Rai G.K., Singh K.R, Rai P.K., Rai S.K.** (2011) Peroxidase, polyphenol oxidase activity, protein profile and phenolic content in tomato cultivars tolerant and susceptible to *Fusarium F. sp. Lycopersici. Pak. J. Bot.*, **43:** 2987-2990.

**Rao Q., Luo C., Zhang H., Guo X., Devine G.J.** (2011) Distribution and dynamics of *Bemisia tabaci* invasive biotypes in central China. *Bull. Entomol. Res*., **101:** 81–88.

**Sercan P., Mustafa G., Golgen B.O.** (2013) The effects of tobacco mosaic virus infection on growth and physiological parameters in some pepper varieties (*Capsicum annuum* L.). *Not Bot Horti Agrobo.,* **41:** 427-433.

**Sofy A.R., Attia M.S., Sharaf A.M.A., El-Dougdoug K.A.** (2014) Potential impacts of seed bacterization or salix extract in faba bean for enhancing protection against bean yellow mosaic disease. *Nature and Science,* **12:** 67- 82.

**Sofy A.R., El-Dougdoug K.A., Mousa A.A., Refaey E.E.** (2017) Impact of two TYLCV Egyptian isolates on metabolic and antioxidant activities in some tomato cultivars. *International Journal of Advanced Research in Biological Sciences,* **4:**22.

**Sofy A.R., Mahfouze S.A., El-Enany M.A.M.** (2013) Isozyme markers for response of wild potato species to potato spindle tuber viroid Egyptian Isolate. *World Applied Sciences Journal,* **27:** 1010-1022.

**Stansley P.A., Naranjo S.E.** (2010) *Bemisia:* bionomics and management of a global pest. *Springer,* **17:** 467-489.

**Šubr Z.S., Nováková H.D.** (2006) Detection of transgene copy number by analysis of the T1 generation of tobacco plants with introduced P3 gene of Potato virus A. *Acta Virology,* **50:** 135-138.

**Sudhakar N., Nagendra-Prasad D., Mohan N., Murugesan K.** (2007) Induction of systemic resistance in *Lycopersicon esculentum* cv. PKM1 (tomato) against Cucumber mosaic virus by using ozone*. J. Virol. Methods.,* **139:** 71-77.

**Sun Y.C., Pan L.L., Ying F.Z., Li P., Wang X.W., Liu S.S.** (2017) Jasmonic acid-related resistance in tomato mediates interactions between whitefly and whitefly-transmitted virus. *Sci. Rep.,* **7:** 566.

**Sun, Y., Guo H., Zhu-Salzman K., Ge F.** (2013) Elevated $CO_2$ increases the abundance of the peach aphid on *Arabidopsis* by reducing jasmonic acid defenses. *Plant Sci.,* **210:** 128–140.

**Tajul M.I., Naher K., Hossain T., Siddiqui Y., Sariah M.** (2011) Toamato yellow leaf curl virus (TYLCV) alters the phytochemical constituents in tomato fruits. *AJCS,* **5:** 575- 581.

**ORCID:**
Samra Mirzayeva: https://orcid.org/0000-0002-1693-4487

*Journal of Life Sciences & Biomedicine, vol. 6(79), No 2, p. 87-93 (2024)*

# COP29 is a global manifestation of solidarity for a green world

**Vagif Novruzov**

*Ganja State University, 454 Heydar Aliyev Ave., AZ2000, Ganja, Azerbaijan*

***For correspondence:*** *vnovruzov1@rambler.ru*

Received: September 7, 2024; Received in revised form: November 14, 2024; Accepted: December 19, 2024

**The article describes the history of the road to COP 29 and the provisions of the Paris Agreement adopted at the 21st conference of the UN Framework Convention on Climate Change. The declaration of 2024 as the "Year of Solidarity for the Green World" in the country by the Decree of the President of the Republic of Azerbaijan, the work done on the 29th "Conference of the Parties (COP)" that we will host, the role of ecosystems in climate change, inventory and protection of biodiversity, as well as the results of scientific research carried out in the direction of preventing species extinction and protecting genetic diversity have been covered in the article.**

***Keywords:*** *COP29, green world, climate change, biodiversity, ecosystems*

## INTRODUCTION

The history of the road to COP 29 and the provisions of the Paris Agreement adopted at the 21st conference of the UN Framework Convention on Climate Change have been described in the paper. According to the Decree of the President of the Republic of Azerbaijan dated February 2, 2021, emphasizing one of Azerbaijan's five national priorities for socio-economic development until 2030, articulated as the "Country of Clean Environment and Green Growth" and also according to the Decree of the President of Azerbaijan Ilham Aliyev dated December 25, 2023, 2024 was declared the "Year of Solidarity for the Green World" in the country. In this approach, the major activity program is constantly focused on restoring contaminated areas, protecting forests, flora and fauna, fertilizing and greening arid lands, and reducing the detrimental consequences of climate change (Order No. 2469 of the President of the Republic of Azerbaijan dated February 2, 2021; Decree of the President of the Republic of Azerbaijan dated December 25, 2023)

In recent years, great efforts have been undertaken in our country to combat climate change. Karabakh, East Zangezur, and the Nakhchivan Autonomous Republic have been **declared "green energy" zones** by the President of the Republic of Azerbaijan. As is well known, the Paris Agreement was adopted at the 21st conference of the Parties to the UN Framework Convention on Climate Change in December 2015. It was decided that the 29th "Conference of the Parties (COP)", hosted by a different country every year, will be held in Baku from November 11 to 22.

Before diving into Cop29, the history of the issue should be taken into account.

In the declaration adopted by the UN member states in September 2000 "Millennium Declaration", in the sections on climate change, biodiversity, desertification, protection of forest and water resources, the optimal strategy for the global environmental crisis that will occur in the 21st century was developed. Azerbaijan joined the Convention on Biological Diversity adopted by the UN Commission on Environment (Rio de Janeiro, 2002) and determined its scientific directions for biodiversity conservation.

Humanity has reached such a stage in its development that scientific and technical progress has had a negative impact on nature, and inefficient use of natural resources leads to fundamental changes on a global scale - there is a

https://doi.org/10.59849/2710-4915.2024.2.87
Available online 31 December 2024

danger of lack of life factors such as soil, water areas, air, flora, and fauna.

The world experience demonstrates that preserving biodiversity, which is the foundation of modern society's existence, is an important indicator of sustainable development and coping with the nature crisis (International Code of Botanical Nomenclature (Vienna Code) 2009,

To expand international cooperation in the field of biodiversity conservation, the Republic of Azerbaijan joined the UN Convention on Biological Diversity in 2000.

This is an actual problem of vital importance for human civilization, including the independent Republic of Azerbaijan. Because biodiversity integrity reflects the stability of ecosystems. The process of mass destruction of natural ecosystems is accelerating.

The State Commission on Genetic Resources of Biological Diversity, chaired by Academician Jalal Aliyev was created, to ensure the implementation of comprehensive measures to prevent the threat of extinction of the genetic resources of plants, animals and microorganisms by Order No. 848 of the National Leader Heydar Aliyev dated December 21, 2001, and "National strategy" was developed. Based on the materials of the commission, the "National Strategy and Action Plan for the Conservation and Sustainable Use of Biodiversity in the Republic of Azerbaijan" was approved by Order No. 1368 of the President of the Republic of Azerbaijan, dated March 24, 2006, and identification of biologically diverse ecosystems in regions and their evaluation for preservation, specifying the list of rare and endangered plant and animal species, ensuring the protection of their gene fund, and the expansion of natural areas, botanical gardens that specially protect them, conducting research on the conservation of biodiversity, organization of the second (2013) and third (2023) editions of the **"Red Book"** of the Republic of Azerbaijan, establishing new botanical gardens in large cities, etc. were set as a goal.

## MATERIALS AND METHODS

Research materials were collected at Ganja State University during the expeditions conducted in the western region of Azerbaijan, and specially protected natural areas (Goygol National Park, Eldar Shami State Nature Reserve, Garayazi State Nature Reserve, Korchay State Nature Reserve), ecosystems, such as forest massifs, river basins, meadows, rocks, and plant litters, freshwater wetlands were separated as a biological monitoring network, scientific-research was continued in the direction of evaluation and forecasting of anthropogenic changes occurring in vegetation. Floristic, floristic-systematic, areological, ecological classical, and modern methods, and The International Code of Nomenclature for Cultivated Plants (2009) were used as the basis for the research. In 2013, the II edition of the "Red Book" of Azerbaijan was published, and in 2023, the III edition was published in connection with the 100th anniversary of the National Leader Heydar Aliyev. The team of Ganja State University actively participated in the preparation of both publications (Novruzov et al., 2013, 2023), the International Code of Nomenclature for Cultivated Plants (Vienna code) (2009).

## RESULTS AND DISCUSSION

The problem is being solved by the joint efforts of the state and the people. Azerbaijan has 10 national parks, 10 state nature reserves, 2 unregistered reserves, 24 state nature sanctuaries, 2,083 trees over 100 years old, 37 geological and paleontological facilities, and 15 thousand hectares of endemic and valuable forest areas. The area of specially protected natural areas in the republic is 594939.1 hectares, constituting 7% of the total area.

In the first edition of the "Red Book" of Azerbaijan, 108 species of animals and 140 species of plants, which are rare, extinct, and endangered, and need to be protected, while in the second edition, 223 species of animals and 300 species of plants, in the third edition, 460 species of plants, 241 species of animals, including the names of 47 species of mushrooms were included. Another feature of the 3rd edition of the "Red Book" is the compilation of pink lists of flora and fauna species in this edition. 51 species of plants, 49 of which are higher and 2 of which are

primitive, are included in this list.

For the first time, it was discovered that the flora biodiversity of the Specially protected areas of the North-Eastern part of the Lesser Caucasus (Goygol National Park, Eldar Shami State Nature Reserve, Garayazi State Nature Reserve, Korchay State Nature Reserve) consists of 1208 species in 465 genera and 107 families and 187 species belonging to rocks and plant litters contain 106 genera in 34 families.

One of the main problems of modern biology in today's conditions, where the burden of anthropogenic impact on the environment is increasing, is to study and understand the species at the cenopopulation level to ensure the conservation and efficient use of biodiversity. Cenopopulation is the real form of existence of the species in nature. The strategy, structure, amount, and age spectrums (4 age periods, 9 age states), dynamics of the cenopopulations of rare grains in the North-east of the Lesser Caucasus were comprehensively studied and evaluated. The seed yield of grains, seed reserve in the soil, and germination capacity were studied, and the advantages of the regeneration of cenosis with seeds were theoretically and experimentally substantiated.

Taking into account the role of rivers in the uneven distribution of climate and relief, an inventory of the flora biodiversity of the river basins of the northeastern slope of the Lesser Caucasus (Kurakchay, Shamkirchay, Goshgarchay, Ganjachay, Aghstafachay), monitoring of rare and endangered species was carried out, the taxonomic structure was clarified, given the modern classification of vegetation, a system of measures for the protection of the gene fund was developed. It was found that the flora biodiversity of the Shamkirchay basin consists of 668 species belonging to 240 genera in 75 families, Kurekchay basin -870 species belonging to 370 genera in 95 families, Goshgarchay basin-410 species belonging to 110 genera in 50 families, Zayamchay basin-445 species belonging to 180 genera in 65 families, Ganjachay basin-602 species belonging to 98 genera in 60 families, and flora biodiversity of the Agstafachay basin was found to consist of 415 species belonging to 97 genera in 37 families, 36 species belonging to 26 genera in 20 families in the Shamkirchay basin, 32 species belonging to 27 genera in 20 families in the Kurakchay basin, 43 species belonging to 28 genera in 22 families in the Goshgarchay basin, 45 species belonging to 24 genera in 13 families in the Zayamchhay basin, 35 species belonging to 21 genera in 14 families in the Ganjachay basin, 36 species belonging to 22 genera in 8 families in the Aghstafachay basin have become rare and are in danger of extinction.

The vegetation of the river basin includes post-forest meadows and shrubs, tall grasses, subalpine meadows and steppes, alpine meadows, rock and plant litter, and forest plants. Each vegetation type is distinguished by unique formations. In the highlands, dozens of formations and associations emerge from understories and form meadows and steppes of various compositions.

Post-forest tall grasses manifest themselves in various forms. Subalpine vegetation is divided into formations, such as subalpine wet meadows, mesophile subalpine meadows, mesophile diverse herbaceous subalpine meadows, and dry subalpine meadows. The species composition of flowering plants is low in rock and plant litter vegetation; they mainly form microgroupings consisting of lichens and mosses. From the vegetation of river basins, 22 species were included in the III edition of the "Red Book" of Azerbaijan from the Ganjachay basin, 15 species from the Zayamchay basin, and 17 species from the Aghstafachay basin (Novruzov, 2020).

Distribution of 142 species belonging to 47 genera in 12 families was found in water meadows and marshy meadows.

For the first time, monitoring was carried out in the "Avey" State Historical-Cultural Reserve, famous for its Damjili spring, located in the territory of Gazakh district, which is rich in historical architectural and archaeological monuments (Fig. 2) The role of vegetation in protecting the ecological balance and regulating the climate was explained and it was considered appropriate to carry out propaganda work in this direction. "Avey" State Historical-Cultural Reserve is named after the "Avey" temple, a relic of the oldest Stone Age, a land of rich historical architecture and archaeological monuments. Archaeological and architectural monuments, as well as moveable and immovable historical and

cultural assets, are regarded as the reserve's primary property in its area. There are hundreds of cultural monuments of the Paleolithic, Mesolithic, Eneolithic, Middle Ages, Bronze, Copper and later historical centuries in these areas. There are 56 registered and dozens of newly discovered monuments in the reserve's territory, of which 1 is of world, 33 of national, and 22 of local importance. 15 of them belong to architectural, 36 to archaeological and 5 to decorative-applied art samples. There are 3 world-renowned monuments in the territory of the Gazakh region, one of which is the Damjili cave camp, covering the oldest period. Damjili cave camp is located in the southeast of Avey Mountain. It is an archaeological and natural monument. Its history dates back to the Paleolithic period. This cave is half-circular shaped, the front part is open. It is under limestone rocks. It is called Damjili Cave because of the drops of water seeping through the natural cracks. "Damjili" cave is a relic of the ancient stone age. The age of Damjili cave is two hundred thousand years ( **https://avey-heritage.az/)**

Along with historical monuments, the reserve is also surrounded by rich vegetation. The role of specific monuments, flora and fauna of the reserve is irreplaceable in the preservation of a clean environment and ecological balance. The reserve is also rich in Avey Mountain, Goyazan Mountain and other monuments. The reserve is considered the most favorable place for tourism. The famous Azerbaijani poet Samad Vurgun called Damjili the 8th wonder of the world and the 1st wonder of Azerbaijan. It is important to organize tours of these areas for visitors to COP29.

The legendary ***Adiantum capillus-veneris* L.** hanging from the ceiling of the cave may be considered the emblem of the Damjili spring. ***Adiantum capillus-veneris* L.** (Maidenhair fern) (Figure 1). It is a short plant with creeping rhizomes and grows in wet places. It is a rare relict species. The leaves are bright green, broad-oblong, and feathery. Its height reaches 50-60 cm. The leaves are symmetrical and feather-shaped. The disks have 3-4 sections. It is light green. Segments are 2.5-3 cm long and 1.5-2 cm wide. Leaf petals are 15-20 cm long, black-brown, glossy, slender. The above-ground parts of the plant are used for scientific purposes and folk medicine. It produces spores all summer until autumn. They reproduce by spores. It grows in a humid environment. It is found in Ganja, in the center of the Lesser Caucasus, on the walls inside the wells. This species is native to North America, the Caribbean, the Mediterranean, Eurasia, and the Middle East . It is appropriate to include what was found for the first time in the reserve, in the new editions of the "**Red Book**" of Azerbaijan. (https://avey-heritage.az/; Red Book of the Republic of Azerbaijan, 2013, 2023)

**Fig. 1.** *Adiantum capillus-veneris* L.

**Fig. 2.** The staff of the Ganja State University and the reserve in Damjili Cave (2024).

Semidesert with warmwood and salsola, and steppes play a major role in the vegetation of the reserve. The dendroflora of the forests consists of white poplar *(Populus alba* L.), black poplar *(Populus nigra* L.), Caucasian walnut *(Pterocaria*

*fraxinifolia* (Lam.) Spach., willow *(Salix caprea* L.), silver berry *(Elaeagnus angustifolia* L.), elm *(Ulmus glabra* Huds.), oak *(Quercus iberica* Stev), juniper *(Yuniperus oblonga),* hawthorn *(Crataegus collina* Charm.), Tussilago, Athel tamarisk *(Tamarix kotschyi Bunge),* barberry *(Berberis vulgaris* L.), garland thorn *(Paliurus* Hill.), peacock flower *(Caesaloina),* dog-rose *(Rosa canina* L), sheep fescue *(Festuca ovina* L., *F.supina* L.), alpine meadow-grass (*Poa alpina* L.), feather grass species (*S.barbata, S.capillata* L., *S.caspia* C.Koch.), blackberry (*Ruscus canensis* L.), White dead-nettle, forage kochia (*Kochia prostrata* (L.) Schrad.), scilla (*Scilla caucasica* Misz.), snowdrop (*Galanthus transcaucasicus* Fomin), goatgrass (*Aegilops* L.), spear thistle *(Cirsium vulgare* L.), eremopyrum (*Eremopurum* Ledeb.), bromus (*Bromus* L.), cheeseweed (*Malva parviflora* L.), valerian (*Valerianella cornicularia* C.A.Mey.), dandelions (*Taraxacum oficinale* Veig.), salsify (*Tragapogon collinus* DC.), rockfoils (*Saxifraga adscendens* L.), corn speedwell (*Veronica arvensis*), catnip (N*epeta cataria*), white dead-nettle (*Lamium album* L.), yarrows (*Achilla biberstenii* Afan.), bentgrass (*Agrostis* L.), Atraphaxis (*Atraphaxis caucasica* (Hoffm.) Pavlov), mulberry (*Morus alba* L., *M.nigra* L.), buttercup (*R.arvensis* L., *R.caucasicus* Bieb.), stinging nettle (*Urtica dioica* L.), Ferula caspica (*Ferula caspica* M.Bieb, from the village of Yukhari Dashsalahli, it is in the Red Book*),* etc. (Asgarov, 2016; Novruzov, 2020; Alverdiyeva, Novruzov, 2014)

The flora of the reserve is rich in lichens and mosses. On large rocks, the following lichen species are widespread: Acarospora badiofusca, *Caloplaca caesiorufa, C.decipiens, C.erythrocarpa, C. ferruginea, V.acrotella, V.floerkeana, V.glaucina, V.ferruginea, Endopyrenium hepaticum, E.rufescens, Endocarpon adscendens, V.nigrescens, Diplischistes ocellatus, Coniocybe grasilenta, Lecidea convexa, L.lapicida, Rhizocarpon cinerovirens, R.geographicum, R.geminatum, L.frustulosa, L.polytropa, Lecanora cenisea və s.,*mamırların *Andrea rupestris, Polytrichum formosum, P.piliferum, Saelania glaucescens, Dicranella heteromalia, Cynodontium polycarpum, Dichodontium pellucidum, Dicranum fuscescens, D.mayus, D.scoparium, Tortella tortuosa, Schistidium convertum* and so on (Alverdiyeva, Novruzov, 2014).

186 species belonging to 36 genera and 25 families were found in the territory of the reserve. Of these, 21 species are trees, 24 are shrubs, and 141 are herbs. 4 species of ferns belonging to 3 genera in 2 families, 18 species of lichens belonging to 11 genera in 9 families, and 12 species of mosses belonging to 11 genera in 10 families were also found in the reserve. 5 formations and 16 associations were observed in the area.

Shir-shir waterfall of the Gadabay district is one of the floristically rich areas that have been studied in recent times and plays an important role in climate regulation (Figure 3).

**Fig. 3.** Shir-shir waterfall of the Gadabay district.

The waterfall is located in the area of the Duzyurd-Miskinli plateau at the foot of the Khachagaya mountain in the middle and high mountain zones of the Lesser Caucasus. Jurassic, Cretaceous, Paleogene and Anthropocene sediments are common. For the first time, monitoring was conducted around the waterfall and Hachagaya (Fig. 4). Hachagaya Mountain is located between Tovuz and Gadabay districts, at an altitude of 2200 meters. *Botrychium lunarium, Ophioglossum lusitanicum, Osmunda regalius, Cheilanthes pteridioides, Asplinium septentronale, Cystopteris montana* of ferns form a storeyed background on the rocks in the waterfall. On the rocks, species of the genera Saxifraga, Campanella, Dianthus,

Heracleum, Sedum, Thymus, Plantago form a characteristic background. Oak (*Quercus sp.*), beech (*Fagus orientalis*), and Caucasian hornbeam (*Carpinus caucasica*) trees are common in the forests. There are subalpine and alpine meadows in the highlands. Forests rise here to 2000 - 2400 m. Caucasian oak (*Quercus macranthera*), oriental beech (Fagus orientalis), silver birch (*Betula pendula*), redbud maple (*Acer trautvetteri*), Sorbus boissieri (*Sorbus boisseri*), bird cherry (*Padus racemosa*) are found in high mountain forests. The subalpine vegetation of the area covers heights of 1800-2600 m. European blueberry (*Vaccinium myrtiUus*), windflower (*Anemone fasciculata*), Betonica (*Betonica orientalis*), glutinous sage (*Salvia glutinosa*), Papaver (*Papaver fugax*), wolfsbane (*Aconitum nasutum*), crested gentian (*Gentiana septemfida*), hungarian mullein (*Verbascum* sp.), Caucasian crane's-bill (*Geranium ibericum*), cornish bellflower (*Campanula alliariifolia*), raspberry (*Rubus idaeus*), heal-all (*Prunella vulgaris*), etc. are found there. The main plants of the Alpine altitude belong to the families of cereals and sedges. These plants create alpine meadows. The main composition of “alpine carpets” is caraway (*Carum caucasicum*), lady's mantles (*Alchemilla caucasica*), plantago (*Plantago saxatilis*), red clover (*Trifolium ambiguum*), sedge (*Carex tristis*), Steven dandelion (*Taraxacum stevenii*), sibbaldia (*Sibbaldia parvifolia*), toothed bellflower (*Campanula tridentata*), sandwort (*Minuartia aizoides*).
*Fauna*. Wild goat ( *bezoar ibex* ) (*Capra aegagrus*), roe deer (*Capreolus capreolus*), brown bear (*Ursus arctos*), wolf (*Canis lupus)* are found in these territories. From birds, bearded reedling (*Panurus biarmicus*), osprey (*Pandion haliaetus*), Spanish sparrow (*Passer hispaniolensis*), rock sparrow (*Petronia petronia*), Caucasian grouse (*Lyrurus mlokosiewiczi*), Caucasian snowcock (*Tetraogallus caucasicus*), etc. are found. The main plants of the alpine altitude belong to the grains and sedge family. These plants create “alpine carpets” there. The main composition of “alpine carpets” is caraway, lady's mantles, plantago, red clover, sedge, Steven dandelion, sibbaldia, toothed bellflower, sandwort (Asgarov, 2016) 214 species of flowering plants belonging to 38 genera of 18 families, 7 species of ferns belonging to 7 genera of 7 families, 21 species of lichens belonging to 18 genera of 9 families, 14 species of mosses belonging to 12 genera of 9 families were found in Shir-Shir waterfall. For visitors to COP29, it is important to organize excursions to these areas.

**Fig. 4.** The staff of the Ganja State University and Dokuz Eylul University of Turkey (Izmir) in the Hachagaya mountain of Gadabay district (2023).

The wonderful Damcili cave, a relic of the ancient stone age with a history of 200 000 years, in the Avey State Historical and Cultural Reserve in the territory of Gazakh region, rich in historical architectural and archeological monuments, and the Shir-Shir waterfall, located on Hachagaya mountain in the Gadabay region, can be considered as an excursion route for the guests coming to COP29. The effect of climate change on the flora and fauna of both areas is clearly observed. It is appropriate to include Adiantum capillus-venereis L. hanging from the ceiling of Damcili cave in the next "Red books" of Azerbaijan.

## REFERENCES

**Alverdiyeva S., Novruzov V.** (2014) Summary of lichens of Azerbaijan. Baku: Elm, 237 p. (in Russian).

**Asgarov A.M.** (2016) The flora of Azerbaijan. Baku: TEAS PRESS, 444 p. (in Azerbaijani).

**Bayramova A.A.** (2013) Flora biodiversity of specially protected natural areas of the western

region of Azerbaijan. Baku: Elm, 2013, 327 p. (in Azerbaijani).

**Flora of USSR** (1934) Andiantum genus. M.: Academy of Sciences of USSR, **V. 1:** 80. -302 (in Russian).

**Hajiyev V.D. et al.** (1990) Highland vegetation of the Lesser Caucasus (within Azerbaijan). Baku: Elm, pp. 23-28 (in Russian).

**International Code of Botanical Nomenclature (Vienna Code)** (2009) M.; Saint Petersburg, 282 p.

**İsmayilova Z.M., Guliyeva R.Z.** (2013) Number and age spectra of cenopopulations of *Agrostis planifolia* C.Koch and *Agrostis lazica* Balansa in various plant associations. *Journal of "Agrarnaya nauka"*, **I:** 23-28 (in Russian)

**Novruzov V.S.** (2020) Flora biodiversity and dynamics of river basins in the northern part of the Lesser Caucasus. *Azerbaijan Journal of Botany*, **I:** 8-12 (in Azerbaijani)

**Novruzov V.S., Aslanova Y.A., Guliyeva R.Z.** (2022) Rock vegetation and plant litter and cenopopulation dynamics of the Lesser Caucasus. Ganja, 210 p. (in Azerbaijani)

**Novruzov V.S., Bayramova A.A**. (2011). The role of specially protected natural areas in the conservation of biodiversity. Baku: Elm, pp.38-46 (in Azerbaijani).

**Novruzov V.S., Guliyeva G.M.** (2017) Cryophilic meadows and tall grass as a special type of intrazonal vegetation. *J. Agrarnaya nauka (M.).* **2:** 20-22:

**Order No. 2469 of the President of the Republic of Azerbaijan dated February 2, 2021,** Decree of the President of the Republic of Azerbaijan dated December 25, 2023.

**Red Book of the Republic of Azerbaijan** (2013, 2023) Baku: Elm

**URL:https://avey-heritage.az/**

**ORCIDS:**
Vagif Novruzov: https://orcid.org/0009-0007-5093-6914

*Journal of Life Sciences & Biomedicine, vol. 6(79), No 2, p. 94-101 (2024)*

# Assessment of the impact of global climate change on soil degradation in Azerbaijan

**Garib Mammadov[1], Movlud Teymurov[2*]**

*[1]Presidium of the Azerbaijan National Academy of Sciences, 10 Istiglaliyyat Str., AZ1001, Baku, Azerbaijan*
*[2]Institute of Geography, Ministry of Science and Education of the Republic of Azerbaijan , 115 H.Cavid Ave., AZ1143, Baku, Azerbaijan*

***For correspondence:** movlud_teymurov@yahoo.com*

Received: September 7, 2024; Received in revised form: November 14, 2024; Accepted: December 19, 2024

**The article is devoted to the assessment of the impact of climate change on soil degradation in Azerbaijan. The research process was carried out using the modern. The assessment with the new methods is carried out taking into account the influence of complex factors on soil cover changes. The study process showed the existence of a very close relationship between the change in climate quantities and soil degradation, and it was possible to reflect these relationships in concrete numerical terms. Changes in climate factors during the years 2000-2022 played a positive role in the process of soil degradation in most cases. During this period, the area of fertile soils decreased by 18.5%. Studies show that as a result of increasing the temperature in the range of about 0.19-0.22°C; with a decrease in precipitation by 16-18 mm the area of fertile soil cover decreases by about 5.8-6.2%. Especially the intervals of temperature 14.3-14.6°C, precipitation 300-450 mm, maximum soil retention 1000-1100 mm are more critical levels and are accompanied by sharper increases in soil degradation. Compared to 2000, in 2022, the area of highly degraded bare soil has grown by 1234.2 km2 (17.3%). In 2050, this increase is predicted to be 27.4% more than in 2022.**

***Keywords:*** *Climate changes, soil degradation, operative-interactive methods, maximum soil retention, Hydrological soil groups*

## INTRODUCTION

As a result of the reforms carried out in the Republic of Azerbaijan, a powerful socio-economic potential has been created in the country. However, against the background of global climate change, the depletion of natural resources creates additional problems in implementing reforms. The gradual decrease in water, land and biological resources creates a serious imbalance with the development of the economy, especially agriculture, and population growth. Constant and continuous study of vital water, land and biological resources and their adequacy to climate change is necessary for the continuous and sustainable implementation of socio-economic reforms. Therefore, research work to solve existing problems is also of great importance. It is clear that under the influence of climate and other factors, the available natural resources will continue to decline. For this reason, scientific directions and methods should be determined so that research does not lag behind the general pace of reform development. At present, modern conditions require the assessment of natural resources with more modern, sensitive and operational methods that can respond to any changes. Taking into account the current trends in world science and their need for Azerbaijan, we have developed the CWBM (Complex water balance method) and IESA (Interactive electronic soil assessment) methods, which are operational-interactive methods (Mammadov et al., 2018; Mammadov, Teymurov, 2019).



https://doi.org/10.59849/2710-4915.2024.2.94
Available online 31 December 2024

It is known that changes occurring in natural complexes, especially in the soil and vegetation cover, are primarily associated with changes in the water and heat balance of the area. The most obvious manifestation of climate change is rising temperatures and decreasing rainfall, resulting in lower levels of moisture in most regions, which in turn leads to land cover degradation.

CWBM was developed on the basis of the leading water balance methods currently available in the world, by synthesizing them and taking into account the specific features of the nature of Azerbaijan. With the CWBM and IESA methods, research is evaluated in a completely new context. Currently, in hydrometeorological and soil assessments, preference is given to hybrid and synthesis methods. New synthesis and hybrid methods offer additional benefits by combining important features of several methods at the same time. These aspects were taken into account when conducting a comprehensive assessment of climate and soil elements. Most of the results obtained by the main methods to which they relate are of high accuracy since they are obtained as a result of long-term observations and experimental research. With the help of CWBM and IESA, containing the best features of the basic methods, it is possible to estimate the moisture regime, heat, and water balance of the area with high accuracy. The study takes into account most of the components that make up the natural and anthropogenic landscapes. In this case, the relationship between all the components included in the complex can be evaluated individually or in a complex way. In this case, it is possible to calculate the causes of changes in land resources (climatic, landscape, anthropogenic, etc.) and the impact of each of them on the change.

## MATERIALS AND METHODS

As an example in the research area, the geospace covered by fragment 188-032 of the Landsat satellite image was taken. This geospace with an area of 37.4 thousand $km^2$ is located in an area covering most of the physical and geographical features of the nature of Azerbaijan. Space images of different years, a digital elevation model (DEM), and hydrometeorological observation data were used as the initial inputs for the study. To determine the types of landscape, land cover, and moisture levels, multispectral space images of the terrain from different periods were processed using normalized difference indices (NDI-Normalized Difference Indices). Considering the content of the research work, difference indices of vegetation (NDVI, SAVI), bare soil and badlands (BSI), erosion (NDBal), soil salinization (NDSI), residential and build-up (NDBI), urban (UI), water (NDWI), drought (NDDI) and moisture (NDMI) were preferred in the study. The elevation, slope and aspect values of the study area were determined using DEM, and the morphometric indicators of the rivers using the Hydrology, Surface and Density software of the ArcGIS program. To select similar data and get more reliable correlations between components, multiple linear regression equations (Multiple Linear Regression) were needed. The main source of climate data is the measurement-observation data of the Ministry of Natural Resources and Ecology of the Republic of Azerbaijan.

## RESULTS AND DISCUSSION

Natural complexes are formed from the close unity of numerous components, and a change in one component necessarily affects others. The essence of the new method lies in the study of intercomponent relationships, taking into account the participation of as many components as possible and achieving this relationship in a specific quantitative expression. Studies show that it is possible to obtain relationships between any components that make up natural complexes in various forms (multiple linear regression, correlation, mathematical, trend forms, etc.). Modern scientific and technical innovations (space information, GIS and other multifunctional technologies) have created conditions for a deeper study of intercomponent relationships. The new method is called the Complex Water Balance Method (CWBM), as the new method comprehensively studies the participation of most of the factors that make up the natural complex and their relationship. Natural and anthropogenic complexes existing in a certain territory are mainly associated with 3 groups of factors:

1) Components that make up the surface

cover of the area. These include LULC (Land use and Land cover), vegetation density, soil cover, granulometric composition of soils and HSG (Hydrological soil groups).

2) Morphometric values. It includes average elevation, slope, aspect of slopes, basin area, river length, horizontal and vertical surface fragmentation, and river network density.

3) Climate and moisture factors. These include air temperature, precipitation, actual and potential evaporation, humidity coefficient, maximum soil water retention, actual soil moisture, hydrological losses, initial abstraction, etc.

The current presentation is dedicated to changes in soil cover as a result of climatic changes. However, the study took into account the influence of other components in addition to climatic influences on soil cover because any area is viewed as a single complex. Figure 1 presents maps of several main components that play an important role in the formation of the soil cover, obtained from satellite images in 2022, climate data, and using GIS technologies.

Using the CWBM and IESA methods, the process of studying the soil-water-air environment is considered as a single mechanism, and the process of assessing soil-climatic factors is analyzed and studied in a completely different context (Teymurov, 2023, pp. 28-32). In traditional scientific approaches, climate factors were estimated based on precipitation and temperature. In modern methods, the concept of "humidity level of the territory" is mainly used. Studies show that assessing the humidity rate of areas only from precipitation and temperature does not give satisfactory results. For example, in areas with a sufficiently high level of precipitation, soil and water can be expressed in small quantities. Or vice versa, in regions with high temperatures, they can be very high. Climate and moisture indicators act as indicators in terms of change and the presence of other components (water, soil, vegetation, etc.). Therefore, the humidity level of territories was estimated using predictors characterizing both air moisture and soil moisture. When assessing the humidity level of the territory among air factors precipitation, temperature, potential evapotranspiration, humidity coefficient; and among soil indicators maximum soil retention, actual soil moisture, HSGs, etc. are accepted as the main indicators. Potential evapotranspiration (M) is the amount of maximum mass of water that can be evaporated into the atmosphere, and maximum water retention (S) - is the highest amount of water that can be stored by the soils under specific natural conditions (Spitalniak et al. 2021).

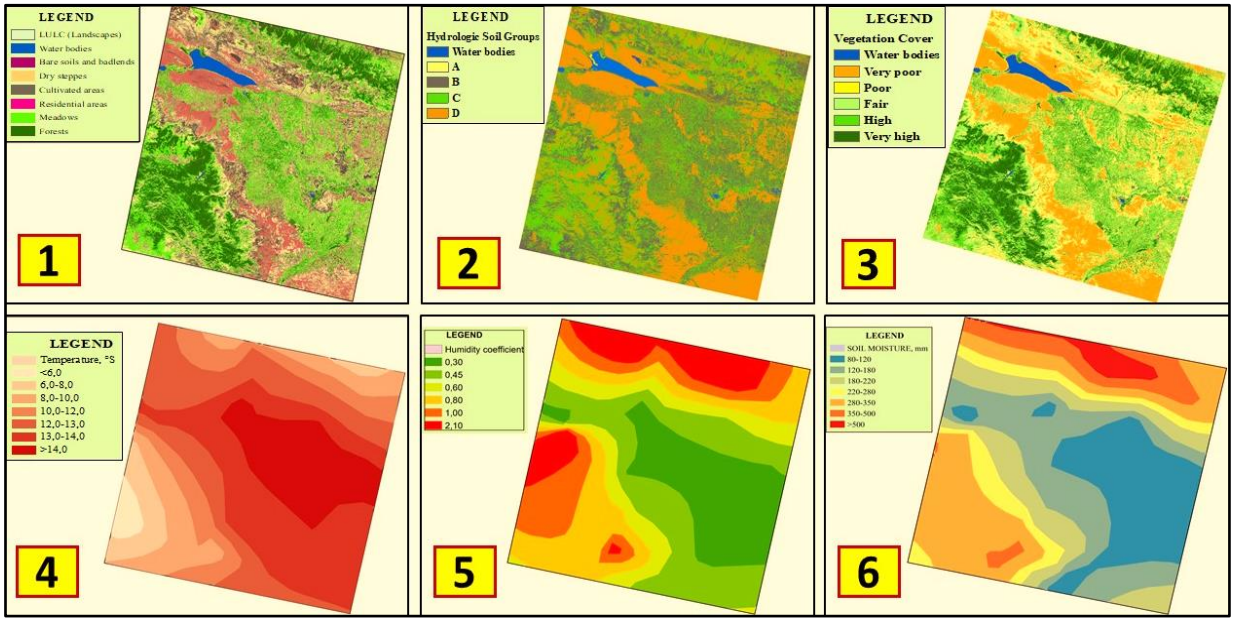


**Fig. 1.** Some important components involved in soil formation: 1-Landscapes; 2-Hydrological soil groups; 3-

Vegetation cover; 4-Air temperature; 5-Humidity coefficient; 6-Soil moisture.

**Table 1.** Changes in soil cover and climatic factors for 2000-2022

| Research object | 2000 | 2022 | Difference, % |
|---|---|---|---|
| Air temperature, °C | 11.5 | 12.7 | +9.45 |
| Precipitation, mm | 580.2 | 521.1 | –10.2 |
| Humidity coefficient | 0.66 | 0.55 | –16.7 |
| Potential evaporation, mm | 873.6 | 955.8 | +8.60 |
| Hydrological soil group (weak infiltration-group D), $km^2$ | 12415 | 14062 | +11.7 |
| Maximum soil water retention, mm | 1012.1 | 1121.0 | +9.71 |
| Actual soil moisture, mm | 236.5 | 200.6 | –15.8 |
| Horizontal surface fragmentation, $km/km^2$ | 1.96 | 2.19 | +10.5 |
| Area of dense vegetation cover, $km^2$ | 5834.4 | 4782.2 | –17.9 |
| Area of fertile soils, $km^2$ | 7843.3 | 6395.4 | –18.5 |

Actual soil moisture (F) is the factual amount of water stored in the soil under existing conditions. The humidity coefficient (R) is expressed as the ratio of precipitation to potential evaporation and is considered the most important parameter in terms of determining the degree of air moisture. The Hydrologic soil group (HSG) is the main indicator in the content of the surface runoff formation and the soil infiltration. In the NRCS classification, 12 soil codes and 4 HSGs (A, B, C, D) are distinguished according to the permeability rate depending on the soil granulometric fraction and porosity. From group A to group D, there is a tendency to weaken infiltration and increase surface runoff.

The collection and processing of the necessary materials in the research work was carried out in the following order:

1) Satellite images of the areas were collected for different periods and their NDI processing was carried out.
2) Maps of soil degradation, vegetation density and climatic factors have been compiled.
3) Climatic and soil-vegetation maps were joined and reclassified, natural conformities were established based on their quantitative changes in different periods.

Table 1 shows the change in soil-vegetation indicators and the most important climatic factors affecting the study area for 2000-2022.

Studies have shown the existence of a very close relationship between the influence of climatic variables and soil cover changes, and these relationships have been reflected in concrete values. Climate change, especially the decrease in air and soil moisture, intensifies the process of soil degradation. It is possible to trace the negative manifestations of the soil cover as a result of climate change, both against the background of an increase in their area and quantitative indicators. As seen in Table 1, the change in climatic indicators that determine the humidity level of the area in 2000-2022 was unfavorable for soil fertility. During this period, there is a negative trend of 8-12% in the change in factors affecting both air moisture and soil moisture. Against the background of a simultaneous decrease in the level of air and soil moisture, the area of dense vegetation decreased by 17.9%, and the area of fertile soil under their combined influence decreased by 18.5%. For 2000-2022, the area of only high-fertility soils decreased by 1447.9 km2, which is 3.87% of the total research area.

Our studies showed that with an increase in temperature by about 0.19-0.22°C; and a decrease in precipitation by 16-18 mm, a moisture coefficient of 0.20-0.23 and soil moisture of 4.3-4.5 mm, the area of fertile soil cover simultaneously decreased by about 5.8-6.2%. Especially in the temperature range of 14.3-14.6°C, precipitation of 300-450 mm, humidity coefficient of 0.35-0.38, soil moisture of 80-120 mm, soil fertility is accompanied by a higher decrease. Before these intervals, the relationship between climatic and soil indicators is mainly in the form of a linear regression dependence, and after the indicated critical limits, it manifests itself in the form of mathematical dependences, accompanied by a logarithmic or other sharp increase. When classifying the most important climatic factors affecting soil cover, low-medium-high intervals were determined: for air

temperature <8°, 8°-12°, >12°C; precipitation <450, 450-850, >850 mm; humidity coefficient <0.6, 0.6-1.0 >1.0; actual soil moisture <120, 120-400, >400 mm; maximum soil retention <800, 800-1100, >1100; potential evaporation <500, 500-1000, >1000 mm. As a result of a decrease in the humidity level, the area of high-quality soils in all cases decreased and the area of low-quality soils increased (Table 2).

Figure 2 shows the changes in maximum soil retention, precipitation and soil fertility, which are the main indicators of humidity level of areas, for the period 2000-2022.

From 2000 to 2022, there were significant changes in the hydrological soil groups (HSGs). An increase by 11.7% in the area of group "D", characterized by poor water permeability, led to a decrease in the infiltration capacity of the territory. This process played an active role in the degradation process significantly reducing soil moisture.

During this period, a serious increase in soil erosion was observed in the area, and horizontal fragmentation of the surface over the entire area increased from 1.96 km/km$^2$ to 2.19 km/km$^2$ (10.5%). The erosion process was most active in cultivated areas, and most weakly in areas with dense forest cover.

**Table 2.** Changes in the humidity level and the area of soil-vegetation cover in 2000-2022 (%)

| Research object | 2000 | | | 2022 | | |
|---|---|---|---|---|---|---|
| | low | average | high | low | average | high |
| | **Air moisture indicators** | | | | | |
| Atmospheric precipitation, mm | 43.7 | 35.9 | 20.4 | 50.3 | 35.2 | 14.5 |
| Air temperature, °C | 7.8 | 27.3 | 64.9 | 5.9 | 23.8 | 70.3 |
| Potential evaporation, mm | 19.4 | 40.7 | 39.9 | 17.5 | 37.8 | 44.7 |
| Humidity coefficient | 45.0 | 35.3 | 19.7 | 52.8 | 30.0 | 17.2 |
| | **Soil moisture indicators** | | | | | |
| Maximum soil water retention, mm | 31.6 | 34.0 | 34.4 | 18.0 | 39.2 | 42.8 |
| Actual soil moisture, mm | 38.0 | 41.5 | 20.5 | 45.5 | 40.9 | 13.6 |
| Infiltration capacity (HSG) | 21.8 | 55.1 | 23.1 | 24.7 | 55.7 | 19.6 |
| | **Change of soil-vegetation cover** | | | | | |
| Soil cover fertility | 35.7 | 43.3 | 21.0 | 42.1 | 41.8 | 16.1 |
| Vegetation density | 50.6 | 33.8 | 15.6 | 62.1 | 27.1 | 10.8 |

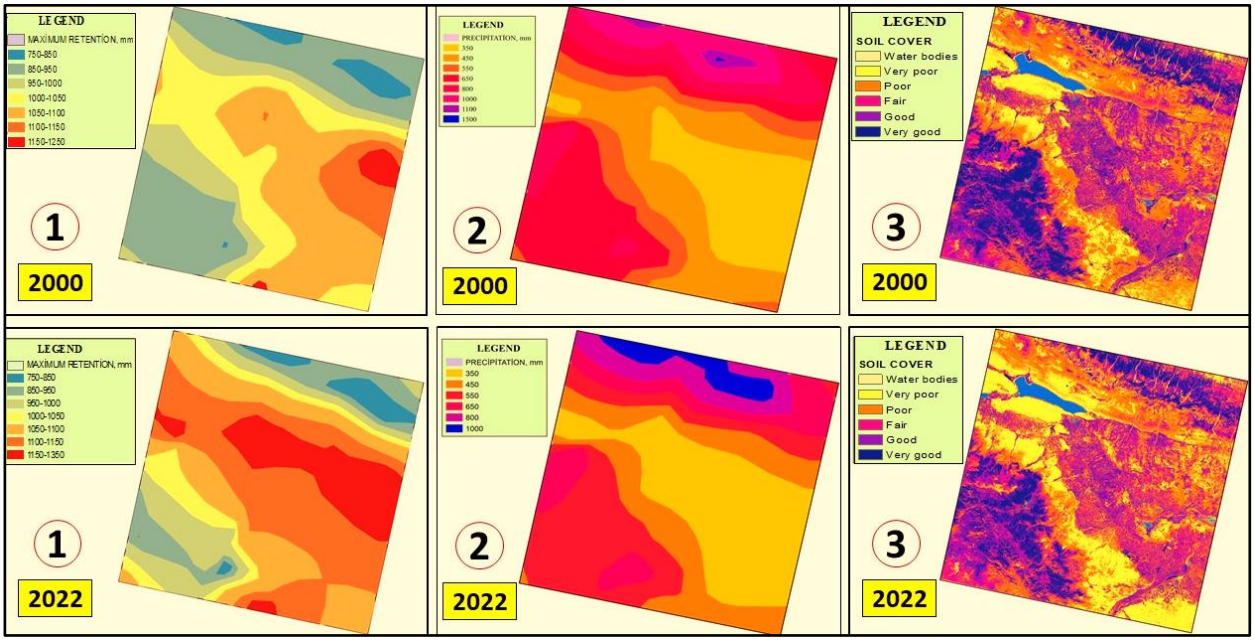


**Fig. 2.** Changes for 2000-2022: 1- Maximum soil retention; 2–Precipitation; 3–Soil cover.

Determining the role of anthropogenic and climatic factors in soil degradation is one of the most difficult scientific problems to solve. In addition, the advantages of the combined use of Analogue terrains, Counter-approach and NDI methods allow you to track the results of natural and anthropogenic impact on changes separately. By combining change maps of various components and reclassifying, it is possible to track the extent of these effects using various software in ArcGIS. Since there are very few natural landscapes left on the plains and foothills, this process is more accurately observed in mid-mountain and high-mountain regions. The analysis of anthropogenic impacts was determined by the way processing and decipher of vegetation (NDVI), moisture (NDMI), erosion (NBaI), salinity (NDSI), drought (NDDI), Karaburun, 2010). During the study years, the effects of climate change manifested themselves faster than the effects of anthropogenic changes. The boundary between climatic and anthropogenic impacts was discovered by comparing land plots with similar physical-geographical conditions, but different land use. The impact of human activities is mainly tested by the change in the area of rural and urbanized settlements, cultivated areas, badlands located in the plains and foothills. The rate of soil degradation is different in areas subject to anthropogenic impact. As can be seen from Figure 1, although negative climatic impacts increased to a greater extent on agricultural lands (yards, crops, pastures) in the study period, the expansion of the area of infertile soils was relatively slow. Various therapeutic measures carried out in these areas could at least partially slow down the growth rate of the degradation process.

The CWBM assessment is based on 3 stages of the study: Previous, Current, and Forthcoming. The study of the physical-geographical conditions of the area from the past period, being carried out in parallel with the modern evaluation, allows the following of the quantitative and qualitative changes that occurred in the past period. At the same time, the reasons for these changes, the assessment of the role of various factors, and the analysis of the mistakes made are the basis. These, in turn, provide additional advantages in terms of predicting and modeling possible changes. The forthcoming studies of the territory are carried out on the basis of a possible change in the direction of landscape, climatic and anthropogenic impacts in a long-term period; changes in the settlement and employment of the population; the content of the upcoming socio-economic and agrarian reforms, etc. At present, in contrast to the traditional three-way forecasts, preference is given to the modern multi-way forecasting model. Modern scientific technologies make it possible to predict millions of options taking into account the influence of complex factors and interactively manage them according to the content of natural and anthropogenic changes and transformations. Table 3 and Figure 3 show the areas of degraded soils based on Previous (2000), Current modern (2022) and Forthcoming (2050) studies of the area. The forecast for 2050 is given with only one of the climate models (CCCM), based on possible landscape changes, the rate of population settlement and the content of expected reforms (Mammadov, 2002; Makhmudov, 2022).

Compared to 2000, in 2022, the area of highly degraded unsuitable lands increased by 17.3% (1234.2 $km^2$). It is predicted that in 2050, this increase will be 27.4% more (2692.8 $km^2$) than in 2022.

**Table 3.** Changes in soil fertility in the study area in different periods

| Soil cover condition | 2000 | | 2022 | | 2050 | |
|---|---|---|---|---|---|---|
| | $km^2$ | % | $km^2$ | % | $km^2$ | % |
| Water bodies | 673.2 | 1.80 | 602.1 | 1.61 | 456.3 | 1.22 |
| Very poor (bare soils) | 5909.2 | 15.8 | 7142.4 | 19.1 | 9834.2 | 26.3 |
| Poor | 7180.8 | 19.2 | 9124.6 | 24.4 | 10767.2 | 28.8 |
| Fair | 8265.4 | 22.1 | 7592.2 | 20.3 | 6244.3 | 16.7 |
| Good | 7517.4 | 20.1 | 6917.3 | 18.5 | 5647.4 | 15.1 |
| Very good | 7854.0 | 21.0 | 6021.4 | 16.1 | 4450.6 | 11.9 |

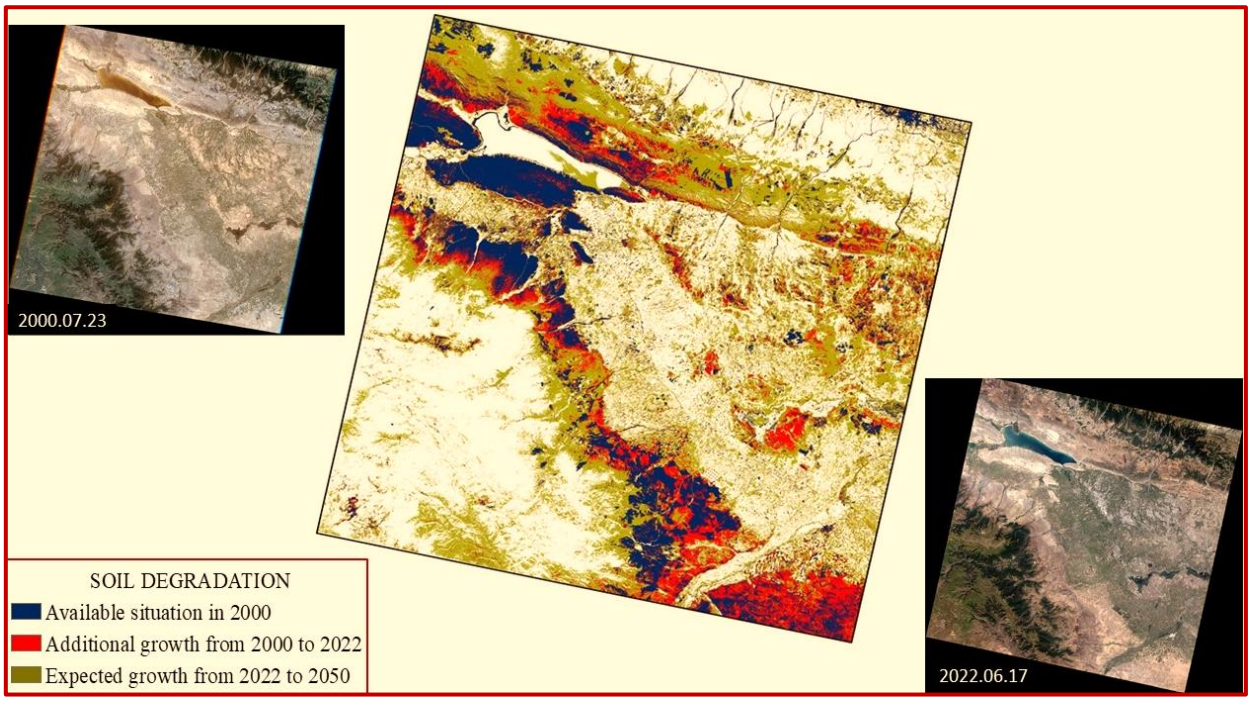


**Fig. 3.** Areas of degraded soils in the study area in 2000, 2022 and 2050

## CONCLUSION

The new method (CWBM) is very important from the point of view of solving many problems, such as the heat-moisture balance of the area, the assessment and forecast of natural resources, the protection of the existing ecosystem, territorial planning, and more efficient management of the use of water, soil and other natural resources. In the CWBM, the entire research process is carried out without spatial and temporal restrictions on the basis of satellite images of the area and GIS technologies. CWBM is an innovative and operational-interactive method. The results obtained with its help are distinguished by their sensitivity and adequacy to any changes, high accuracy. The advantages of the new method make it relevant to popularize and expand the use of the possibilities of its application.

## REFERENCES

**Karaburun A. (**2010) Estimation of C factor for soil erosion modeling using NDVI in Buyukcekmece Watershed. *Ozean Journal of Applied Sciences*, **3 (1):** 77-85.

**Makhmudov R.N.** (2022) Regional climatic changes in Azerbaijan and their impact on the rivers regime. *Slovak İnternational Scientific Journal*, **63:** 48-54.

**Mammadov G.Sh.** (2002) Agrarian reforms in Azerbaijan: legal and scientific-environmental issues. Baku: Science publishing house, 412 p.

**Mammadov G.Sh. et al.** (2018) Guidelines for mapping interactive electronic soils and ecological assessment of soils based on CiS technologies. Baku: Science publishing house, 80 p.

**Mammadov R.M., Teymurov M.A.** (2019) Assessment of water resources and risk of water losses due to climate changes and human activities. *The Scientific Heritage Journal* (Budapest, Hungary), **3(34):** 3-12.

**Rivera M.A.O. et al.** (2023) Application of the normalized difference vegetation index with satellite imagery in Warints-Yawi. *Communities Mathematical Statistician and Engineering Applications*, **72 (1):** 88-97.

**Spitalniak M., Bogac A., Zięba Z.** (2021) The assessment of water retention efficiency of different soil amendments in comparison to

water absorbing geocomposite. *Materials* (Basel), **14 (21):** 6658.

**Teymurov M.A.** (2022) The value of ınıtıal abstractıon and estımatıon of run-off formıng raınfall rate at a specıfıc geographıcal locatıon. *Journal Science, Education and Innovation in the Context of Modern Problems*, **5 (4):** doi: 10.56334/sei/6.1.4.

**Teymurov M.A.** (2023) Assessment of soil-vegetation cover and water resources on the basis of modern scientific innovation. *Scientific advances and innovative approaches Proceedings of the III International Scientific and Practical Conference*. Japan: Tokyo, pp. 28-32.

**Trong C.N. et al.** (2021) A modified bare soil ındex to ıdentify bare land featuresduring agricultural fallow-period in Southeast Asia using Landsat 8. *Land*, **10 (3):** 1-18.

**ORCIDS:**
Garib Mammadov: https://orcid.org/0000-0003-1340-2394
Movlud Teymurov: https://orcid.org/0009-0008-2038-2321

*Journal of Life Sciences & Biomedicine, vol. 6(79), No 2, p. 102-113 (2024)*

# The problems of desertification of soil-plant cover as consequences of climate change

**Tubukhanim Gasimzade**

*Presidium of the Azerbaijan National Academy of Sciences, 10 Istiglaliyyat Str., AZ1001, Baku, Azerbaijan*

***For correspondence:*** *nushana_kasimova@yahoo.com*

Received: September 30, 2024; Received in revised form: November 25, 2024; Accepted: December 18, 2024

**An analysis of botanical groups, the composition of associations and formations of desert and semi-desert vegetation and soil cover of the flat part of the Shirvan zone of Azerbaijan was carried out during the research. The state of soils and plant species composition of associations were established. Saline soils are developed in semi-deserts on the Shirvan plain under dry subtropical climatic conditions. The desert vegetation type of the Shirvan territory is zonal in nature and is formed by 2 formation classes, 6 formations and 19 associations, and the semi-desert vegetation of the Shirvan territory is formed by 3 classes, 3 formations and 9 associations were revealed as a result of the research.**

***Keywords:*** *Desert, semi-desert, aridization, climate change, vegetation and soil cover*

## INTRODUCTION

Desertification is the degradation of “land” in arid and semi-arid regions of the globe, caused by both anthropogenic and natural factors and processes. The concept of "land" in this case means a bioproductive system consisting of soil, water, vegetation and other biomass, as well as ecological and hydrological processes within the system (Description, Causes, & Impact…..). Now, the world is facing an acute problem of aridization, that is the advance of the desert, as a consequence of which there is a decrease in biomass, productivity, and species diversity as a result of targeted climate change or intensive economic activity. These vulnerable ecosystems are important with unique features and resources. They include deserts, semi-arid soils, mountains, wetlands, small islands and some coastal areas. Destruction of vegetation due to lack of energy, intensive grazing, inadequate irrigation systems, unregulated farming, poor agricultural practices and other causes accelerate the desertification process. The process of various types of desertification is taking place on 3,741 thousand hectares of the territory of the republic (National Atlas of Azerbaijan, 2016). The main reasons for this are water erosion (34.3%), irrigation erosion (3.2%), wind erosion (4.3%) (National Atlas of Azerbaijan, 2016). This process has accelerated in recent decades in the Kur-Araz lowland, the Absheron Peninsula and the territory of the Nakhchivan Autonomous Republic, which have an arid and semi-arid climate and where agriculture is most developed. As a result, the lands subject to desertification have reached a size of 36% to 43.3% (3,741 thousand hectares) in the last 30 years (Gasimzade, 2015). So, a desert is a zonal type of landscape that has developed under conditions of moisture deficiency (arid desert) or heat (cold desert) and is characterized by the sharp amplitude of daily and annual air temperatures, favorable for plant development. 23% of the earth's surface is classified as typical deserts according to updated UNESCO data (UN Convention, 1994). The desert is considered a characteristic type of Eastern Transcaucasia. There is also the concept of "semi-desert", which is a transition from the



https://doi.org/10.59849/2710-4915.2024.2.102
Available online 31 December 2024

desert to the steppes.

If earlier the concepts of "semi-desert" and "desert" characterized only the landscape, then recently it is also understood as the plant types common in the territory. Thus, these concepts have a dual nature and are accepted as landscape-geographical (regional) and geobotanical terms (www.britannica.com). Deserts and semi-deserts have an excessively dry climate, saline and solonchak soil cover from a geographical point of view. The soil contains various salts in significant quantities. The amount of sand in the soil is greater. The average annual precipitation is low. The average air temperature is high. The abundance of the thermal effect in the desert and the low level of atmospheric moisture depend not only on zonal climate changes, but also on the nature of the substrate, the nature of moisture, water permeability, and the absorption of water from the air. Therefore, the nature of the substrate plays an important role in the formation of the desert. Most researchers classify deserts and semi-deserts as areas where the natural selection of life forms is developed in drought resistance (Smolander, 2005).

## MATERIALS AND METHODS

The natural and geographical landscapes of the Gobustan, Hajigabul, Kurdemir, Ujar, Zardab, Goychay, Agdash, Yevlakh, Akhsu districts of the Shirvan territory of Azerbaijan were chosen as the object of study. Research methods: expeditions, semi-stationary and office stages and laboratory studies. The soil-vegetation of the studied territory was classified and geobotanical descriptions were selected for ecobiological analysis (Yaroshenko, 1961, 1969; Beideman, 1960; Haciyev, Gasimova, 2008). The studies were conducted under field route conditions with GIS coordinates indicated. The materials of the Flora of the USSR (Flora of the USSR, 1934-1960), the Caucasus (Grossheim, 1950), Azerbaijan (Flora of Azerbaijan 1950-1961), modern literary and internet catalogues, as well as a number of other sources were used under identifying the species. Number of standard methods were used in the course of geobotanical studies, when studying the current state of the species population and assessing the cenopopulation: accordings to V.A.Yurtsev (Yurtsev, 1975), and to R.V.Kamelin (Kamelin, 1973). The abundance of vegetation in the formation is given according to the five-point system of A.A.Grossheim (Grossgeim, 1932), the phenological phases of vegetation in the species composition of the formation are indicated in the following order: veg. - vegetation; flow. - flowering, fruit. - fruiting (Beideman, 1960).

## RESULTS AND DISCUSSION

Semi-deserts extend to an altitude of 1000 (1100) – 1300 (1600) m a.s.l. The main factors influencing semi-desert vegetation are moisture deficit, high summer temperatures and soil salinization. The amount of annual precipitation in the semi-desert zone does not exceed 200-300 mm. Precipitation occurs in the spring and autumn periods. Ephemeral plants develop and enrich the forage quality of winter pastures during this period. The dry period lasts 4-5 months here. Saline soils are developed in semi-deserts on the Shirvan plain under dry subtropical climatic conditions. Saline soils are mainly distributed as spots with different contours in the area of zonal meadow-steppe and gray-brown soils and cover 1.3%-1.5% of the territory. As a rule, saline soils are distributed in low parts, close to the surface of the level of saline groundwater, or in most cases, in depressions protruding to the surface. Samples of this type were taken in the Hajigabul district (samples were taken on the territory of the urban municipality of Hajigabul, arable land, longitude 48º52′33″, latitude 40°3′22″) at depths of 0-18,18-68,68-108, 108-141, 141-186 cm.

Soil moisture is within 3.9%. Humus content is very low, in the upper layers – 1.90%, in the lower layer it decreases to 0.48%. Carbonate content in the upper and lower layers is 14-15%, in the middle layers it increases to 17.9%. The sum of absorbed bases increases from 24.85 to 39.15 from the upper to the lower layer, respectively. According to the granulometric composition, at <0.001, the upper layer indicator is 9.88, in the second layer - 11.00, in the third and fourth 10.44 and 10.22,

respectively, and in the lower layer it decreases to 9.94, and at <0.01, the values by layers in the first are 33.58, in the second - 37.60, in the third - 35.68, in the fourth - 38.50, in the lower layer - 32.52, respectively.

The flat part of the territory is classified as clayey desert and semi-desert types according to general physical and geographical conditions. The soils of saltwort deserts are, in most cases, solonchaks, and form a transition to zonal gray-brown desert soils (Gasimzade and Ibadullayeva, 2015; Gasimzade, 2015).

Such complex ecological conditions lead to the development of plant groups with a simple composition in semi-deserts. Simple semi-desert formations are replaced by more complex semi-desert wormwood groups in the western and south-western parts, with relatively high humidity, as a result of improved soil conditions. After the end of the vegetation period of ephemerals in May, perennial plants, especially subshrubs and shrubs, begin to develop in semi-deserts. Perennial plants, especially subshrubs and shrubs, begin to develop in semi-deserts after the end of the vegetation period of ephemerals in May. The most common are of the cereals: *Poa pratensis* L., *Bromus japonicus* Thumb., *Lolium rigidum* Gaud., *Eremopyrum orientale* (L.) Jaub.&Spach., *E.triticeum* (L.) Jaub.&Spach., *Agropyron cristatum* (L.)Gaertn., and also *Plantago ovata* L., *Silybum marianum* L., *Calendula arvensis* L.

So, semi-desert vegetation is widespread in the central part of Shirvan (at the foot of the Lesser Garamin Range).

To the north of the Kura river, close to the mountain foot, semi-desert vegetation forms a wide strip parallel to the Kura river, i.e. desert vegetation is replaced by semi-desert, which depends on the degree of salinity of the upper soil layer and on the relief. Desert phytocenosis is found in convex and semi-desert phytocenoses - in hollow relief.

From the left bank to the foot of the mountain on the convex parts of the relief, white wormwood joins the caragana thickets, where the botanical content of ephemeral synusia increases and tiers are formed, resulting in the formation of wormwood-saltwort-ephemeral phytocenosis.

On the convex part of the relief, as a result of the decrease in the degree of salinization of the upper soil layer (0-20 cm), caragana leaves the wormwood-saltwort-ephemeral phytocenosis and forms a wormwood-ephemeral phytocenosis. The wormwood-ephemeral phytocenosis predominates as a result of the decrease in the degree of salinization of the upper soil layer. Classification of semi-desert vegetation in the research area:

Type: Semi-desert

I. Formation class: *Salsola wormwood*

Formation: *Salsoleta – Artemisietum*

Association:

1. *Artemisia fragranso – Salsola dendroidesum*
2. *Artemisia fragranso – Salsola nodolosum*
3. *Artemisia fragranso – Climacoptera crassosum*
4. *Artemisia fragranso – Petrpsimonia brachiatosum*

II. Formation class: *Ephemerality*

Formation: *Hordetum*

Association:

1. *Hordeum leporinumoso – Lolium rigidiumosum*

III. Formation class: Epherality-wormwood

Formation: *Artemisietum*

Associations:

1. *Artemisia fragransum*
2. *Artemisia fragranso – herbosum*
3. *Artemisia fragranso – Ephemerotosum*
4. *Artemisia fragranso – Tripleurospermum perforatosum*

The woody saltwort-wormwood formation covers the slightly saline soils of the study area. The edificatory of the formation is white wormwood (*Artemisia lerchiana* Web.)– perennial plant, height (25) 30-45 cm. The formation is represented by 4 associations in the area *Artemisia lerchianoso – Salsola dendroidososum*; *Artemisia lerchianoso – Salsola nodulososum*; *Artemisia lerchianoso – Climacortera crassosum*; *Artemisia lerchianoso – Retrosimonia brachiatosum.*

The edificatory of the *Salsola arborescens – Artemisia alba* association is a subshrub – *Artemisia alba* Turra, the dominant is *Salsola arborescens* L.

The association includes 22 species, which

cover 12 families (*Chenopodiaceae, Roaceae, Fabaceae, Asteraceae, Alliaceae, Geraniaceae, Malvaceae, Papaveraceae, Apiaceae, Ranunculaceae, Fumariaceae, Scrophulariaceae*).

The following families predominate in terms of the number of species: *Rosaceae* – 5 species, *Asteraceae* – 4, *Fabaceae* – 3, *Chenopodiaceae* – 2. The remaining 8 families are represented by 1 species.

There are 4 tiers in the association. In the first tier – *Salsola dendroides* Pall. with an abundance of 2 and an average height of 50 cm. the dominant of the association. *Artemisia lercheana* Weber. (some authors note as *A.arenaria* DC. but in the world flora online *A.lercheana* Weber.) is located in the second tier with an abundance of 3, an average height of 30 cm. This tier also includes *Salsola nodulosa* Iljin. In the third tier with an abundance of 1-2, an average height of 9-25 cm are located from ephemerals and ephemeroids - *Poa bulbosa* L., *Aegilops triuncialis* L., *Lolium rigidum* Gaudin, *Alhagi pseudoalhagi* (Bieb.) Fisch., *Allium affine* Ledeb., *Gagea tenufolia* (L.) Ker Gawl., *Adonis bienertii* Butkov, *Papaver phoeas* L. etc. The fourth tier is represented by lichen – *Parmelia vagans* (Nyl.) Hale, and moss – *Barbula unguiculata* Hedw.

Grey soils rich in $CaCO_3$ are developed on the convex parts of the relief in the area of the ephemeral wormwood phytocenosis study.

The formation has been presented by 4 associations: *Artemisetum–Herbosum*; *Artemisetum–Erhemersoum*; *Artemisetum-Salsosum, Artemisetum-Petrosimonosum.*

The floristic composition of the ephemeral-white wormwood association includes over 30 species, which cover 16 families: *Asteraceae, Poaceae, Scrophulariaceae, Fabaceae, Apiaceae, Liliaceae, Amaryllidaceae, Iridaceae, Ranunculaceae, Fumariaceae, Hypecoaceae, Brassicaceae, Frankeniaceae, Geraniaceae, Plantaginaceae, Chenopodiaceae*. The most common species are *Poaceae* – 7, *Asteraceae* – 5, *Scrorhulariaceae* – 3 species, *Apiaceae* и *Fabaceae* families have presented by 2 species, other 11 families by 1 species. The species composition of the *Artemisia lerchianoso – Efemeretosum* association (Fig.1) with the participation of the dominant *Artemisia arenaria* DC. is given in Table 1.

**Fig. 1.** *Artemisetum–Erhemersoum*

**Table 1.** The species composition of the association *Artemisetum – Herbosum*

| Species | Abun-dance | Tiers height (in cm) | Phenological phase April-May |
|---|---|---|---|
| **1** | **2** | **3** | **4** |
| Subshrub | | | |
| *Salsola dendroides* | 2 | I (35 cm) | veg. |
| Semi-bushes | | | |
| *Artemisia lerchiana* | 3 | I (32 cm) | veg. |
| Cereals | | | |
| *Poa bulbosa* | 1-2 | II (17 cm) | flow.-fruit. |
| *Hordeum lerorinum* | 1 | II (19 cm) | flow. |
| *Bromus yaponicus* | 1 | II (15 cm) | flow. |
| *Lolium rigidum* | 1-2 | II (20 cm) | fruit. |
| *Anisantha rubens* | 1 | II (20 cm) | fruit. |
| *Aegilors cilindrica* | 1 | II (22 cm) | flow. |
| *Eremopyrum triticeum* | 1 | II (16 cm) | flow.-fruit. |
| Legumes | | | |
| *Vicia cinerea* | 1 | II (20 cm) | flow.- fruit. |
| *Medicago minima* | 1 | II (10 cm) | flow.- fruit. |
| Motley-grass | | | |
| *Gagea tenuifolia* | 1 | II (12 cm) | flow.- fruit. |
| *Allium rubellum* | 1 | II (12 cm) | flow.- fruit. |
| *Iris acutiloba* | 1 | II (10 cm) | flow. |
| *Adonis aestivalis* | 1 | II (25 cm) | flow. |
| *Fumaria schleicheri* | 1 | II (20 cm) | flow.-fruit. |
| *Hypecoum pendulum* | 1 | II (20 cm) | flow.- fruit. |
| *Strigosella africana* | 1 | II (12 cm) | fruit. |
| *Parentucella latifolia* | 1 | II (14 cm) | flow.- fruit. |
| *Veronica rolita* | 1 | II (7 cm) | flow.-fruit. |
| *V. amoena* | 1 | II (10 cm) | flow.-fruit. |
| *Calendula persica* | 1 | II (9 cm) | fruit. |
| *Tragorogon graminifolius* | 1 | II (21 cm) | flow. |
| *Tripleurospermum perforatum* | 1 | II (12 cm) | veg. |
| *Plantago ovata* | 1 | II (6 cm) | flow.-fruit. |
| *Scandix pecten – veneris* | 1 | II (17 cm) | flow.-fruit. |

*Continued table 1*

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| *Torilis nodosa* | 1 | II (20 cm) | flow. |
| *Frankenia rulverulenta* | 1 | II (10 cm) | flow. |
| *Erodium cicutarium* | 1 | II (25 cm) | flow.-fruit. |
| *Scorzonera laciniata* | 1 | II (20 cm) | flow. |
| *Strigosella africana* | 1 | I (15 cm) | flow.-fruit. |
| *Calendula persica* | 1 | I (10 cm) | flow.-fruit. |
| *Sonchus oleraceus* | 1 | I (40 cm) | flow. |

The vegetation is formed from xeromesophytes and xerophytes that evident from the species composition of this phytocenosis. White wormwood is a xerophyte, and ephemerals and ephemeroids are xeromesophytes. Cereals are represented here by 8 species, legumes by 3 species, and motley grass by 19 species. Hence the conclusion that motley grass predominates in the phytocenosis.

Analyzing this phytocenosis by life forms, it turns out that annuals are represented by 20 species, biennials by 3 species, and perennials by 10 species. The total projective cover of the phytocenosis is 60-80%, of which 25-40% is organized from edificator wormwood, 20-30% from subedificators, 10-15% from ephemerals and ephemeroids.

Two-tier ephemeral phytocenosis is developed on the convex part of the relief of the studied territory. The floristic composition of the formation includes 25 species belonging to 12 families in spring (in the last decades of April) (*Poaceae, Fabaceae, Asteraceae, Brassicaceae, Ranunculaceae, Geraniaceae, Scrophulariaceae, Apiaceae, Plantaginaceae, Paraveraceae, Hypecoaceae, Boraginaceae*). Families predominate in terms of the number of species: *Poaceae*–6 species, *Asteraceae* – 4, every from *Fabaceae, Brassicaceae, Geraniaceae, Ranunculaceae* families by 2 species, other 7 families - monospecies.

The dominant species in the phytocenosis are members of the *Poaceae* family. However, the dominant species in the phytocenosis can be replaced depending on annual and seasonal precipitation. The formation has two tiers. The first tier (with an average height of 20-30 cm) is organized from ephemerals and ephemeroids. This tier includes *Poa bulbosa* L., *Lolium rigidum* Gaudin., *Sisymbrium runcinatum* Lax. ex DC., *Plantago lanceolata* L., *Veronica amoena* L., *Calendula persica* L., second tiers (below 1cm) organized from mosses (*Barbula unguiculata sp.* Hedw.) and lichens *Parmelia vagans* (Nyl.)Hale. The formation is represented by annuals - 23 species, and perennials - 3 species according to life forms. Ephemerals and ephemeroids also play a significant role in the formation of desert vegetation (Fig. 2).

**Fig. 2.** Wormwood - ephemeral semi-desert fragment

The main forage reserve of winter pastures is ephemeral. Among them are very valuable forage plants related to legumes, cereals and motley grass. Changes in the amount of these species are associated with seasonal rains. It can be concluded that the semi-desert vegetation of the Shirvan territory is formed by 3 formation classes, 3 formations and 9 associations.

Below are the classification schemes of desert vegetation of the study area:

Vegetation type: Desert

*Formation class*: *I* – Annual swede and saltwort

*Formation*: *Suaedietum*

*Association* :

1. *Suaeda confusoso – Petrosimonia brachiatosum*

2. *Suaeda confusosum*

*Formation*: *Salicornetum*

*Association*:

1. *Salicornia europerosa – Suaeda confusosum*

2. *Salicornia europerosum*

*Formation*: *Petrosimonietum*

*Association*:

1. *Petrosimonia brachiatoso – Climactera crassosum*
2. *Petrosimonia brachiatoso – Suaeda confusosum*
3. *Petrosimonia brachiatoso – Salsola dendraidesosum*
4. *Petrosimonia brachiatosum*

*Formation*: *Climacopteretum*

*Association*:

1. *Climactera crassosum*
2. *Climactera crassososo – Petrosimonia brachiatosum*

*Formation class*: *II – shrubs, bushy sweda and saltwort*

*Formation*: *Suaedetum*

*Association*: *Suaeda microphyllosa – Petrosimonia brachiatosum*

*Formation*: *Salsoletum*

Associations formed by the *Salsola nodulosa* (Moq.) Iljin and *Salsola dendroides* Pall. species are found in areas belonging to the *Salsola* L. genus:

*Association*:

1. *Salsola nodulososum*
2. *Salsola nodulososo – Ephemeretosum*
3. *Salsola nodulososo – Petrosimonia brachiatosum*
4. *Salsola nodulososo – Artemisia fragransosum*

*Association*:

1. *Salsola dendroidesoso – Ephemeretosum*
2. *Salsola dendroidesoso – Alhagi pseualhagiosum*
3. *Salsola dendroidesoso – Petrosimonia brachiatosum*
4. *Salsola dendroidesoso – Artemisia fragransosum*
5. *Salsola dendroidesoso – Halostachys belangerianum*.

*Suaedetum* formation. This formation is typical for desert vegetation, common in saline soils, forms an independent grouping, participates in saltwort semi-deserts and deserts. However, in comparison with other formations, it is not widespread. The edificatory of the formation is *Suaeda microrhylla* Pall. The formation has been presented by 1 association:

*Suaeda microrhylloso - Petrosimonia brachiatosum* (Fig. 3). The association includes shrubs, subshrubs, subbushes, cereals and motley grass, of which 10 species are annual and 4 species are perennial. The total projective cover is 40-50%.

*Suaeda microrhylla* Pall. dominated by 2-3 abundance in the first tier, with an average height of 60 cm. Also participating in this tier is *Tamarix ramosissima* Ledeb. – abundance 1, with an average height of 100 cm. In the second tier, there are 1-2 abundant cereals and motley grass with a height of 10-40 cm: *Bromus japonicus* Thunb., *Petrosimonia brachiata* (Pall.) Bunge, *Suaeda confusa* L., *Malvalthaea transcaucasica* L., *Torilis nodosa* (L.) Gaertn, etc.

**Fig. 3.** *Suaeda microrhylla* Pall.- *Petrosimonia brachiata* (Pall.) Bunge

Lichens *Fulgensia fulgeus* are noted on the soil surface, from mosses – *Barbula unguiculata* hedw.

The species composition of the association *Petrosimonium ramosa – Sueda microphylla* is given in the following table with the participation of the dominant species *Suaeda microphylla* (Table 2).

Valuable forage plants are well eaten by sheep and cattle (*Anisantha rubens*, *Bromus japonicus* Thunb., etc.) on winter pastures, included in the formation, flowering in early spring.

*Salicornietum* formation. Halohyrophilic vegetation is widespread and found in pure and mixed phytocenosis of the saltwort formation in the wet saline depressions of the study area. We collected saltwort in the wet saline areas of the Garasu and Padar villages.

The dominant of the formation is –

*Salicornia europeae* L. (Fig. 4). *Climacopteretum* formation covers a wide area of the desert. It is distributed mainly in saltwort and saline soils. The dominant plant of the formation is the annual plant *Climacoptera crassa* (Bieb.) Batsch.

**Table 2.** Species composition of the *Suaeda mycrophylloso – Petrosimonia brachiatosum* association

| Species | Abundant | Tiers height (in cm) | Phenological phase April-May |
|---|---|---|---|
| Shrubs | | | |
| *Tamarix ramosissima* | 1 | I (100 cm) | veg. |
| Bushes | | | |
| *Suaeda microphylla* | 3 | II (30 cm) | veg. |
| *Anabasis aphylla* | 1 | II (20 cm) | veg. |
| Subshrubs | | | |
| *Salsola dendroides* | 1 | II (40 cm) | veg. |
| Cereals | | | |
| *Hordeum leporinum* | 1 | II (17 cm) | flow. |
| *Anisantha rubens* | 1 | II (10 cm) | fruit. |
| *Bromus japonicus* | 1 | II (17 cm) | fruit. |
| Motley grass | | | |
| *Petrosimonia brachiata* | 2 | II (14 cm) | veg. |
| *Suaeda confusa* | 2 | II (12 cm) | veg. |
| *Torilis nodosa* | 1 | II (11 cm) | flow.-fruit. |
| *Lagoserus glaucescens* | 1 | II (8 cm) | flow. |
| *Malvalthaea transcaucasica* | 1 | II (9 cm) | flow. |

**Fig. 4.** *Salicornia europeosum* L.

The association is represented by 22 species: 18 species are annual and biennial, 4 species are perennial. The projective cover is 30-40% (Fig. 5). The formation is characterized by a sparse grass cover, which is the reason for the poorly developed tiring in them.

*Salsoletum* formation is formed in different ecological conditions, in arid subtropical regions resistant to salinization, drought and heat, in most cases on saline rocks and is widespread in the foothills of the sole, according to the mechanical composition and it is formed in heavy, saline, dry soil.

**Fig. 5.** *Climacoptera crassa* (Bieb.) Batsch.

The edificatory of the formation is - *Salsola nodulosa* (Moq.) Iljin. The formation of *Salsoletum nodulosae* L. can be considered as a genetic stage developing in saline soils from the point of view of differentiation of soil horizons replacing each other and decomposition of salts.

However, recent studies have proven that in the central part of the territory of Shirvan, as well as in the ecosystem we are studying, the *Salsoletum* formation dominates in different ecological conditions and is represented by the 4 associations.

The mentioned ephemeral-gengis association is represented by 23 species. In the first tier there is an abundance of 3, dominant gengiz (*Salsola nodulosa* L.), with an average height of 28 cm. In the second tier there are an abundance of 1-2 - *Phalaris brachystachis* Link, *Avena eriantha* Durieu, *Hordeum lerorinum* L., etc., medium height 10-17 cm, motley grass: with abundance 1-2 *Allium rubellum* M.Bieb, *Tripleurospemum perforatum* L., *Torilis nodosa* (L.) Gaertn., etc., medium height 7-15 cm. The total projective cover is 30-50% (Fig.6).

Independent groupings on the territory are organized from ephemerals (pure or mixed), growing among gengiz shrubs of the gengiz layer and form gengiz semi-deserts.

Intensive development of ephemerals and ephemeroids begins, which gives the cenosis a special beauty after winter hibernation, in early spring, due to precipitation.

Due to aridity, in summer, aspects of the cenosis change. Thus, at the end of May, due to the withering of ephemerals and ephemeroids, the soil cover is exposed. As a result, the gengiz grouping is painted in a gray-green flow. Gengiz bears fruit and gives the cenosis a grey-reddish background in autumn. The grey becomes livelier by the end of autumn, ephemerals and ephemeroids turn green due to precipitation, and in winter, due to frosts, development is suspended.

**Fig. 6.** *Salsola nodulosa* (Moq.) Iljin

This means that the aspect of the gengiz formation is determined in development together with ephemerals and ephemeroids in spring, edificatory gengiz in summer, gengiz and perennials in autumn, ephemerals and ephemeroids in winter.

*Salsoletum* formation is a characteristic plant grouping for the study area, growing in a species composition saline to varying degrees on gray and gray-meadow soils.

The edificatory of the formation is *Salsola dendroides* Rall. Representatives of vegetation of different life forms, groups, forming the composition of the flora of the caragana formation: shrubs – *Halostachys belangeriana* (Moq.) Botsch., *Tamarix ramossima* Ledeb., *Lucium ruthenicum* Murray; bushes – *Salsola nodulosa* (Moq.) Iljin, *Kalidium capsicum* Moq., *Suaeda microphylla* (Pall.) C.A.Mey.; subshrubs and subbushes – *Salsola dendroides* Pall., *Camphorosma lessinqii* Litvinov, *Halocnemum strobilaceum* (Pall.) M.Bieb., *Artemisia fragrans* Willd., *Atriplex turcomanica* (Moq.) Boiss.; perennial herbs – *Aeluropus repens* (L.) Thwaites, *Ae. tittoralis* (gouan) Parl. *Limonium scoparium* (Pall. Ex Willd.) H.Arnaud, *Alhagi pseudoalhagi* (m.Bieb.)Desv. Ex Wangerin, *Cynodon dactylon* (L.)Pers.; ephemeroids – *Poa bulbosa* L., *Allium rubellum* M.Bieb; summer-autumn vegetation – *Climacoptera crassa* (M.Bieb) Botsch, *Gamanthus pilosus* (Pall.) Bunge., *Salsola soda* L., *Petrosimonia brachiate* (Pall.) Bunge, *Suaeda altissima (*L.)Pall, *S. confuse* Iljin; ephemers – *Anisantha tectorum* (L.) Nevski (*Bromus tectorum* L.), *Bromus yaponicus* Thunb., *Hordeum leporinum* L., *H. geniculatum* All., *Phleum paniculatum* Huds, *Lepidium perfoliatum* L., *Limonium spicata* Mill., *Eremopyrum orientale* (L.) Jaub. & Spach., *E.triticeum (*Gaertn.)Nevski, *Adonis aestivalis* L., *Filago spathulata* C.Presl., *Hernaria hirsute* L., *Erodium ciconium* (L.) Her., *Aegilopus squarrosa* L., *A.cylindrica* Host, etc.

In most cases, caragana and wormwood have the same abundance and accompany each other. Two types of mixed wormwood-caragana associations are formed as a result of the merger of the caragana and wormwood deserts. Wormwood is a stronger edificatory, and therefore, displacing caragana to the foothills of the mountains, it replaces it and turns first into a caragana-wormwood, and then into a purely wormwood association. This means that despite the fact that caragana formations have existed in the area for many hundreds of years, they are replaced by wormwood deserts in the process of natural development. Therefore, caragana deserts are considered a transition to a wormwood desert. All varieties of the caragana desert flora of the Kura-Araz Lowland are formed from 82 species of higher plants, most of which belong to the *Poaceae, Chenopodiaceae, Asteraceae* families, etc. (16). One of the characteristic features of caragana deserts is the presence of cereal ephemerals. The species composition of the formation includes glycophytic and halophytic ephemerals.

Glycophytic cereal ephemerals and ephemeroids are found in the least saline soils: *Anisantha rubens* (L.) Nevski, *Hordeum leporinum* L., *Lolium rigidum* Gaudin., *Poa bulbosa* L., etc. Halophytic elements are found in the most saline soils: *Eremopyrum orientale* (L.) Jaub. & Spach., *Plantago loflingii* L., etc. Ephemerals usually form a tier with an average height of 8-14 cm. 5 associative groups have been established in the composition of the caragana association depending on the relief features, high soil salinity, high temperature, low humidity: associative group of caragana with annual saltworts (trichohydrophytes); associative group of caragana with perennial herbs, subshrubs and shrubs (phreatophytes); associative group of caragana with ephemerals and ephemeroids (ambrophytes); associative group of caragana with subshrub saltworts (phreatophytes, trichohydrophytes, ambrophytes); associative group of caragana with subshrub wormwoods (ambrophytes).

A wide area is occupied by wormwood-caragana, saltwort-caragana and ephemeral-caragana associations among the indicated groups. The association formed by caragana with ephemerals, ephemeroids is not widespread in the study area and occurs in the form of spots. The association is widespread on gray-brown, saline- gray soils. The species composition of the ephemeral-caragana association with the participation of the dominant *Salsola dendroides* Pall. (Fig. 7) is given in the table below (Table 3).

**Fig. 7.** *Salsola dendroides* Pall.

The association includes 21 species: subshrubs – 1, cereals – 6, motley grass – 14 species. Of these, annuals and biennials are represented by 18 species, perennials – by 3 species. The total projective cover is 40-60%. *Salsola dendroides* Pall. association edificatory - the first tier is abundantly filled with 3, height 40cm. The second tier is made up of ephemerals-ephemeroids with an abundance of 1-2 - *Lolium rigidum* Gaudin., *Hordeum leporinum* Link, *Bromus yaponicus* Houtt height 14-22 cm; and from the motley grasses with an abundance of 1 and a height of 12-30 cm the following predominate - *Stellaria media* (L.) Vill., *Adonis aestivalis* L., *Sisymbricum loeselii* L., *Medicago minima* (L.) L., *Geranium pusillum* L., *Erodium cicutarium* (L.) L.Hier., etc. In the last tier on the soil surface there are lichen – Nyl.) Hale, and moss – *Barbula unguiculata* Hedw. (Table 3).

**Table 3.** Species composition of the *Salsoleta dendroideso – Ephemeretosum* association

| Species | Abundant | Tiers height (in cm) | Phenological phase April-May |
|---|---|---|---|
| Subshrubs | | | |
| *Salsola dendroides* | 3 | I (45 cm) | veg. |
| *Cereals* | | | |
| *Poa bulbosa* | 1-2 | II (17 cm) | flow.-fruit. |
| *Anisantha rubeus* | 1-2 | II (18 cm) | fruit. |
| *Lolium rigidum* | 1-2 | II (15 cm) | flow. |
| *Bromus japonicus* | 1 | II (19 cm) | flow. |
| *Hordeum leporinum* | 1 | II (20 cm) | flow.-fruit. |
| *Phleum raniculatum* | 1 | II (22 cm) | flow. |
| Motley grass | | | |
| *Petrosimonia brachiata* | 1 | II (16 cm) | veg. |
| *Geranium rusillum* | 1 | II (17 cm) | flow. |
| *Erodium cicutarium* | 1 | II (25 cm) | flow.-fruit. |
| *Sisymbrium loeselii* | 1 | II (28 cm) | flow. |
| *Adonis aestivalis* | 1 | II (30 cm) | flow. |
| *Stellaria media* | 1 | II (14 cm) | flow. |
| *Medicago minima* | 1 | II (12 cm) | Цвет |
| *Leridium vesicarium* | 1 | II (16 cm) | flow.-fruit. |
| *Trirleurospermum perforatum* | 1 | II (19 cm) | flow.-fruit. |
| *Strigosella africana* | 1 | II (18 cm) | flow.-fruit. |
| *Malva neglecta* | 1 | II (20 cm) | flow. |
| *Anagallis arvensis* | 1 | II (13 cm) | flow. |
| *Scandix pecten – veneris* | 1 | II (20 cm) | fruit. |
| *Parentucella latifolia* | 1 | II (13 cm) | flow.-fruit. |

The association formed by caragana with

subshrub wormwoods (ombrophytes) is relatively common in foothill areas, in gray-brown, slightly saline soils. Groundwater is located at a depth of 5-8 m. The association of white wormwood with caragana involves 17 species. In the first tier with an abundance of 3 and an average height of 42 cm, the dominant of the association is located - *Salsola dendroides* Pall. In the second tier, with an abundance of 2, and an average height of 35 cm, the subedificator of the association is *Artemisia lerchiana* Weber. In the third tier - with an abundance of 1-2, and an average height of 12-17 cm, it is located from cereals - *Poa bulbosa* L., *Aegilors truncialis* L., *Phalaris minor* Retz., *Hordeum leporinum* Link, and from the motley grass with abundance 1 and an average height of 10-35 cm *Medicago minima* (L.) L., *Allium rubellum* M.Bieb, *Papaver phoeas* L., *Sisymbrium irio* L., *Erodium hoefftianum* C.A. Meyer, *Torilis nodosa* (L.) Gaertn., *Senecio vernalis* Waldst. &Kit. etc.

The association formed by caragana with annual saltworts (*trichohydrophytes*) is common on meadow soils with a saline surface and is represented by 13 species: the ratio between annuals (9) and perennials (4) exceeds two times. Groundwater is located at a depth of 2.5-3.5 m. The total projective cover is 60%.

Formation class – *Salsola* L. Formations with saltworts occupy a wide space in the desert vegetation type of the studied territory. The development of vegetation depends on annual meteorological conditions, primarily on the amount of precipitation in annual saltwort deserts. Then the vegetation will be sparse, and in the case of heavy precipitation, there will be an abundance of vegetation if there is drought during the growing season. Annual saltwort deserts are represented by 4 formations and 10 associations in the study area. Of the formations common in annual saltwort deserts, the following are dominant: *Climacoptera crassa* (Bieb.) Batsch, *Petrosimonia brachiata* (Pall.) Bunge, *Salicornia europaea* L., *Suaeda confusa* L.

*Suaedetum* formation is most common in annual saltwort deserts of the studied territory. Mainly form thickets in saline solonchaks, sandy, saline soils.

The dominant of the formation is *Suaeda confusa* İljin. Formation is represented by two associations: a) *Suaeda confusoso – Petrosimonia brachiatosum*; b) *Suaeda confusosum* (fig. 8).

The *Petrosimonium ramosa-Sweda tangled* association includes 16 species: 12 species (75%) are annual, 4 species (25%) are perennial. The total protective cover is 20-35%.

The first tier is occupied by *Halostachys belangeriana* (Moq.) Botsch. with an abundance of 2 and an average height of 110 cm (Fig. 9). The second tier with an abundance of 1 and an average height of 27 cm is occupied by *Suaeda microrhiylla* Pall. This tier also includes the dominant *Suaeda confusa* Iljin. with an abundance of 4 and an average height of 20 cm; from cereals - with an abundance of 1 and an average height of 20-30 cm *Aegilops triuncialis* L., *Eremopyrum orientale* (L.) Jaub.&Spach., etc., and from motley grass with an abundance of 1 and an average height of 12-35 cm - *Petrosimonia brachiata* (Pall.) Bunge, *Torilis nodosa* (L.) Gaertn, *Salicornia europaea* L., *Limonium meyeri* (Boiss.) Kuntze, *Climacoptera crassa* (Bieb.) Batsch, *Cerastium perfoliatum* L.), etc.

**Fig. 8.** *Suaeda confusa* L.

**Fig. 9.** *Halostachys belangeriana* (Moq.) Botsch.

One of the main formations in small shrub saltworts is the *Halostachisetum* formation. This formation is formed by the Caspian saltwort, which is a tall halophyte, common in wet solonchaks and saline soils. The Caspian saltwort forms a wide strip on the road in the direction of the Kurdamir district in the studied area. The edificatory of the formation is *Halostachys belangeriana* (Moq.) Botsch. Formation is represented in the studied area by 3 associations: *Halostachis belangerianoso – Tamarix ramosissimosum*; *Halostachis belangerianoso – Erhemerotosum*; *Halostachis belangerianosum*.

The ephemeral-saltwort association includes about 21 species: shrubs are represented by 2 species, subshrubs by 1 species, bushes by 1 species, cereals by 6 species, and motley grass by 11 species. Of these, 16 species are annual and biennial, and 5 species are perennial. The projective cover is 30-40%.

The first tier is occupied by the dominant *Halostachys belangeriana* (Moq.) Botsch. with an abundance of 3 and an average height of 120 cm. This tier also includes *Tamarix ramosissima* Ledeb. The second tier includes *Suaeda microphylla* (Pall.) C.A.Mey. with an abundance of 1 and an average height of 30 cm. The third tier includes *Aeluropus littoralis* (Gouan) Parl, *Eremopyrum triticum* (Gaertn.) Nevski, *Lolium rigidum* Gaud., *Bromus japonicas* Thumb, etc. with an abundance of 1 and an average height of 10-30 cm, and a variety of motley grass: *Salicornia europaea* L., *Climacoptera crassa* (Bieb.) Batsch, *Petrosimonia brachiata* (Pall.) Bunge, *Atriplex sagittata* L., *Suaeda confusa* L., *Sisymbrium loeselii* L., *Salsola soda* L., *Gamanthus pilosus* (Pall.) Bunge, etc.

## CONCLUSIONS

1. The main species that form associations and formations of semi-desert and desert vegetation in the flat part of the Shirvan zone of Azerbaijan were identified as a result of the analysis of botanical groups.
2. The desert plant types of the Shirvan territory are zonal in nature and the desert type is formed by 2 formational classes, 6 formations and 19 associations, semi-desert type – 3 formational classes, 3 formations and 9 associations have been revealed in results of the research.
3. The obtained data indicate the problems of desertification in the studied region, which is inevitably associated with climate change. Considering that the Shirvan region is the food base of the Republic it is necessary to increase the vegetation cover and promote the rational use of biotic resources in areas subject to or affected by desertification and drought, in particular, on the basis of such measures as afforestation, agro- and community forestry, as well as programs for the conservation of vegetation, and the implementation of phytomeliorative work.

## REFERENCES

**Beideman I.N.** (1960) Study of plant phenology. *Field geobotany*, **2:** 333-368 (in Russsian)

**Description, Causes, & Impacts** | Britannica, www.britannica.com

**Flora of Azerbaijan** (1950-1961). Baku, Vols. I-VIII (in Russsian).

**Flora of the USSR** (1934-1960) Moscow, Leningrad: USSR Academy of Sciences, **Vols. I-XXX** (in Russsian).

**Hajiyev V.D., Gasimova T.E.** (2008) Dictionary of the flora of Azerbaijan. Baku: 269 P.

**Gasimzade T.E.** (2015) Eco-biological assessment of main forage grain grop and legumes in pastures hayland of Shirvan

territory. *Journal of Biology and Life Science*, (Macrothink Institute, Las Vegas, Nevada United States), **6(2):** 148-159.

**Gasimzade T.E., Ibadullayeva S.L.** (2015) Regularities of the desertification processes in Shirvan territory of Azerbaijan. *J. Agrarian science* (Georgia, p. 40-43.

**Grossgeim A.A.** (1932) Essay on the vegetation of the Kura-Araks lowland. In Soils of the Kura-Araks lowland.Tiflis, 4: 57-125. (in Russian)

**Grossheim A.A.** (1950) Flora of the Caucasus. Vols. **III,IV,V,VI,VII.** Moscow-Leningrad. – (in Russsian)

**Kamelin R.V.** (1973) Floristic analysis of the natural flora of mountainous Central Asia. Leningrad: Science, 355 p. (in Russsian)

**National Atlas of Azerbaijan,** BCF, 2016, P.444

**Smolander A. et al.** (2005) N and C transformations in long - term N - fertilized forest soils in response to seasonal drought. *Application Soil Ecology*, **29(3):** 225-235.

**UN Convention to Combat Desertification** (1994) UN Conference on Environment and Development (UNCED), June 17, 1994, Rio de Janeiro, *SciDev. Net*., 62 p.

**Yaroshenko P.D.** (1961) Geobotany (Basic concepts, directions and methods). Moscow-Leningrad: Publishing house of the USSR Academy of Sciences, 474 p. (in Russsian)

**Yaroshenko P.D.** (1969) Geobotany. Moscow: Education, 200 p. (in Russsian)

**Yurtsev B.A.** (1975) Some tendencies in the development of the method of specific floras. *Botanical Journal*, **60(1):** 69-83 (in Russsian)

**ORCID:**
Tubukhanim Gasimzade: https://orcid.org/0000-0001-8922-821X

*Journal of Life Sciences & Biomedicine, vol. 6(79), No 2, p. 114-119 (2024)*

# Molecular study of IDUA, IDS, GALNS and GLB1 gene mutations in the Azerbaijan population

**Sevda Alizada[1], Shirkhan Musayev[2], Elkhan Rasulov[2]**

[1]*Azerbaijan Medical University, 167 Samad Vurgun Str., AZ1022, Baku, Azerbaijan*
[2]*GENOM Clinic Laboratory, White City, 3 Central Bulivard, AZ1025, Baku, Azerbaijan*

***For correspondence:*** *alizadasevda@yahoo.com; lab@genom.az; dr.rasulovelkhan@gmail.com*

Received: September 16, 2024; Received in revised form: October 17, 2024; Accepted: December 6, 2024

**For the first time in the Azerbaijan Republic, we carried out medical genetic consultation of affected children suspicious of lysosomal storage diseases, and particularly with mucopolysaccharidoses. Patients were from the cities of Baku, Gyandzhe and other areas of the Republic. Consultations were done by doctors: pediatrician and geneticist. As to clinical manifestations, 19 index patients and 54 members in their families: Hurler syndrome (1 patient), Hunter syndrome (5 patients), Morquio syndrome (13 patients). The NGS (Next Generation Sequencing) technique was used for molecular genetic diagnostics. In index patient suspicious with Hurler syndrome (MPSI) mutation of alpha-L-iduronidase (IDUA) (NP_000194,2: c.1882C>T, p.Arg628Ter) was identified in the homozygous state. Among patients with clinical manifestations of Hunter syndrome (MPSII) three mutations iduronate-2-sulfatase (IDS) gene: 1106C>G (p.Asp358Leu), c.322T>G (p.Asp358Leu) and c.1215del (p.Leu*34406Phefs) were identified in the hemizygous state. In patients with Morquio syndrome (MPSIVA) 9 mutations of the N-acetylgalactosamine-6-sulfatase (GALBS) gene and one mutation beta-galactosidase (GLB1) c.176G-A (p.Arg59His) Morquio syndrome (MPSIVB) were identified. Nine mutations are as follows: c.1144C>G (p.Leu382Val), c.1265A-G (p.Gln422Arg), c.463G-T (p.Gly155Cys), c.1018 G-T (p.Gly340Cys). c.157G>A (p.Gly53Arg), c.553C>T (p.Pro185Ser), c.443A>G (p.His148Arg), c.1283A>G (p.Gln428Arg), c.439T>A (p.Trp147Arg). When examining affected children's family members, 41 people with heterozygous carriage of the GALNS gene were identified: MPS 3, MPSII-12, MPSIVA-26, relatively. In one sibling of the index patient with Morquio syndrome (MPSIVA) c.463G-T (p.Gly155Cys) mutation was found in the homozygous state. Obtained experimental results allow doctors to direct patients to proper treatment as well as prophylactic activities with families including fetus prenatal diagnostics in the next pregnancies.**

***Keywords*****:** *Hurler syndrome, Hunter syndrome, Morquio syndrome, gene, missense mutation, enzyme*

## INTRODUCTION

Mucopolysaccharidosis (MPS) is a group of rare lysosomal storage inherited diseases. There are several types of disease that occur because of corresponding lysosomal enzyme activity deficiency and lead to damage of glycosaminoglycans (GAG) degradation (Caciotti et al., 2018; Zanetti et al., 2021). MPS I (Hurler syndrome, Hurler/Scheie, Scheie) occurs because of the alpha-L-iduronidase enzyme of the IDUA gene, located in the short shoulder of Chromosome 4 in locus 4p16.3. Damage of alpha-L-iduronidase enzyme activity leads to dermatan sulfate and heparan sulfate storage in body cells and tissues. The heritage type is autosome recessive (AR). The frequency of disease among live newborns is 1:100 000-1.5:500 000. The fraction of MPS I among all MPS types consists of 15% (Martins et al., 2018; Puckett et al., 2021). MPS II (Hunter syndrome) arises because of iduronate-2-sulfatase lysosomal enzyme



https://doi.org/10.59849/2710-4915.2024.2.94
Available online 31 December 2024

deficiency. The given enzyme (IDS) is in the long shoulder of Chromosome X (Xq28). The heritage type is X-linked recessive (XR). Average populational frequency varies in the range of 1.5-2:100 000 live newborns.

Among all MPS patients, Hunter syndrome (MPS II) comprises 56% (Noh et al., 2014; Fenton-Navarro et al., 2017). Morquio syndrome (MPS IV) averagely consists of 10% of all affected with MPS diagnosis. The disease starts with a deficiency of two lysosomal enzymes: N-acetylgalactosamine-6-sulfatase (MPS IVA) and beta-galactosidase (MPS IVB) coded by GALNS and GLB1 genes, relatively. N-acetylgalactosamine-6-sulfatase activity deficiency leads to keratan sulfate storage. The ratio of frequencies MPS IVA/MPS IVB is 6/1. The inheritance type is AR. The prevalence average is 1.53-2:100000 live newborns. In developed countries, newborn neonatal screening is carried out for MPS complication rate (Hendriksz et al., 2015; Filocamo et al., 2018; Chien et al., 2020; Kubaski et al., 2020).

The goal of our research was the identification and study of the genetics of Hurler syndrome (MPS I), Hunter syndrome (MPS II), and Morquio syndrome (MPS IV) for patients from the population of the Azerbaijan Republic.

## MATERIALS AND METHODS

Genetic research patients were revealed during medical genetic consultation of affected children with any clinical manifestations of mucopolysaccharidosis. Medical genetic examinations of patients were carried out in the presence of doctor pediatrician and doctor geneticist in children's medical centers in Baku, Gyandzhe cities as well as central clinics in Sheki-Zagatala, Guba-Khachmas, Lankaran-Astara, Shirvan and Mughan economical zones of Azerbaijan Republic. Nineteen affected children with clinical manifestations of Hurler syndrome (1 index patient), five index patients with Hunter syndrome, and thirteen index patients with Morquio syndrome. Fifty-four family members were also examined.

To confirm suspicious clinical manifestations, DNA-level genetic analysis was applied. A genetic study was carried out with the GSN (Next Generation Sequencing) technique. To isolate DNA, a QIAamp DNA Blood mini kit (Germany manufactured) was used. Analysis was carried out on the panel-designed MiSeq Illumina apparatus manufactured by Illumina® (USA). The panel included the following genes: GALNS, IDUA, IDS, GALC, SUMF1, GAA, GUSB, GBA1, GLB1, ARSB, PAH, SMPD1, ADGRV1 and PLA2G6. Sequencing of GALNS, IDUA, IDS, and GBA1 genes on the DNA level was identified with the NGS technique (Next Generation Sequencing). There were used the following kits and programs: kit - Lysosomal Storage Disease Kit, Celemics®; Analysis Platform – MiSeq Sequencing, Illumina®; Analysis programme - SEQ analysis platform, GENOMIZE® (http://seq.genomize.com), GRCh37(h19) (Alizada and Rasulov, 2023).

"DNA samples with their gene mutations were identified on that panel with the Next Generation Sequencing technique. More than 99% of gene coding sites were studied with a reading depth of not less than 50X. The mean reading depth was 1559 indications. The analysis included exon-intron linkage (±10 np)." The pathogeny classification of the obtained results was conducted correspondently to "Guidelines of ACMG®".

## RESULTS AND DISCUSSION

Our results of molecular genetic studies of affected children with Hurler, Hunter and Morquio diseases are presented in Table 1. There are presented types of mucopolysaccharidoses syndromes as well as genes, mutation types on gene and synthesized protein levels, gene pathogeny rate, and gene location in chromosome and its heritance type.

An affected kid with Hurler syndrome had got nucleotide change of Cytosine to Thymine in position 1882 of exon 1 in the IDUA gene in a homozygous state (c. 1882C>T/c. 1882C>T). In consequence of missense mutation/nonsense mutation in newly synthesized protein, a substitution occurred – Arginine amino acid changed with Tyrosine in position 628 (NP_000194.2: p. Arg628Ter). The parents of the affected kid were cousins.

Nevertheless, the population of the

Azerbaijan Republic and the Islamic Republic of Iran have intrinsic ethnic factors in subgroups, there were none among identified patients with Hurler syndrome having c. 1882C>T IDUA gene mutation. However, the given mutation was found among patients in the Republic of Turkey and was one of ten identified mutations of the IDUA gene (Church et al., 2013; Atçeken et al., 2016).

It was established that the most spread type of changes (56.9%) in the IDUA gene was missense mutation/nonsense mutation. The authors studied 292 IDUA genes and managed to find out the following mutation types: splicing - 15.8%, regulator -0.3%, small deletion, small insertion - 23.6%, large deletion, large insertion - 2.4%, complex rearrangements - 1% (Puckett Y. et al., 2021).

The description of Alshahran H. et al. (2023) for MPSI screening of 618 newborns in Kuwait was carried out in the course of 2021-2022 years to evaluate activity levels for the alpha-L-iduronidase enzyme.

Enzyme deficiency was stated to be present in 20 newborns. Molecular study of newborns with enzyme deficit identified IDUA gene c.1882C>T mutation. The frequency of MPS I in the USA was 0.29:100,000 live newborns. In some countries of the world neonatal screening of newborns is being held for the presence of MPSI (Hendriksz et al., 2015; Galimberti et al., 2018).

Three mutations of the IDS gene were identified in five patients during our studies. They had been diagnosed with MPS II: c. 1106C>G (p. Asp358Leu), c. 322T>G (p. Asp358Leu) and c. 1215del (p. Leu*34406Phefs). There were two missense/nonsense mutations and one deletion.

F.Kubaski et al. (2020) in studies of 659 affected patients with Hunter syndrome stated the highest frequency of missense mutation/nonsense mutation of the IDS gene (49.8%). The rest mutation types were distributed as follows: splicing - 9.3%, regulator - 0%, small deletion, small insertion - 11.5%, large insertion, large deletion - 8.8%, complex re-arrangement - 3%.

**Table 1.** Identified IDUA, IDS, GALNS, and GLB1 gene mutations in the Azerbaijan population

| MPS type | Gene, mutation | Protein | Pathogeny | Chromosome, Inheritance type |
|---|---|---|---|---|
| MPS I Hurler syndrome | IDUA: alpha-L-iduronidase NM_000203.5: c.1882 C >T; Exon 1 | p.Arg628Ter | Pathogenic (class 2) | Chr 4p16.3, AR |
| MPS II Hunter syndrome | IDS: iduronate 2-sulfatase NM_000202.5: c.1215del | p.Leu*34406Phefs | Pathogenic (class 1) | Chr Xq28, X-R |
| MPS II Hunter syndrome | IDS: iduronate-2-sulfatase. NM_000202.5: c.322T>G | p.Tyr108Asp | Pathogenic (class 1) | Chr Xq28, X-R |
| MPS II Hunter syndrome | IDS: iduronate-2-sulfatase. NM_000202.5: c.1106C>G | p.Asp358Leu | Pathogenic (class 1) | Chr Xq28, X-R |
| MPS IVA Morquio syndrome | GALNS: N-acetyl galactosamine 6-sulfatase, NM_001323544.1: c.1144C>G | p.Leu382Val | Pathogenic (class 1) | Chr 16q24.3, AR |
| MPS IVB Morquio syndrome | GLB1 beta-galactosidase, NM_000404.4; c.176G-A; Exon | p.Arg59His | Pathogenic (class 1) | Chr 3p22.3, AR |
| MPS IVA Morquio syndrome | GALNS: N-acetyl galactosamine 6-sulfatase, ENST00000268695, c.1265A-G | p.Gln422Arg | Pathogenic (class 1) | Chr 16q24.3, AR |
| MPS IVA Morquio syndrome | GALNS:ENSG00000141012-NM-0011323543, c. 463G-T | p.Gly155Cys | Pathogenic (class 1) | Chr -16q24.3, AR |
| MPS IVA Morquio syndrome | GALNS:ENSG00000141012-ENST00000268695, c.1018 G-T | p.Gly340Cys | Pathogenic (class 1) | Chr -16q24.3, AR |
| MPS IVA Morquio syndrome | GALNS NM_001323544.1: c.157G>A | p.Gly53Arg | Pathogenic (class 1) | Chr -16q24.3, AR |
| MPS IVA Morquio syndrome | GALNS: NM_001323544.1: c.553C>T | p.Pro185Ser | Pathogenic (class 1) | Chr -16q24.3, AR |
| MPS IVA Morquio syndrome | GALNS:NM_001323544.1:c.443A>G Exon 5 | p.His148Arg | Pathogenic (class 1) | Chr -16q24.3, AR |
| MPS IVA Morquio syndrome | GALNS:NM_001323544.1: c.1283A>G | p.Gln428Arg | Pathogenic (class 1) | Chr -16q24.3, AR |
| MPS IVA Morquio syndrome | GALNS:NM_001323544.1: c.439T>A | p.Trp147Arg | Pathogenic (class 1) | Chr -16q24.3, AR |

When examining Taiwan specifically screening iduronate-2-sulfatase enzyme activity authors found 195 cases of the disease. At the same time, 140 asymptomatic cases were revealed. The genetical analysis stated 19 new mutations including c. 1106C>G (p. Asp358Leu) (Lin et al., 2009).

The genetic mutation c.322 T-G is also one of the many mutations linked with Hunter syndrome. This disease is faced mainly in male patients. It leads to damage to various parts of the human body. This mutation causes tyrosine-to-aspartic acid to change in position 108. That change damages the ability to break down GAGs.

The following statistics may be observed if we analyzed the prevalence of Hunter syndrome globally: the United States ranked first in terms of Hunter syndrome cases until 2017. There were 503 cases of the said syndrome. The second place was given to Japan (309 cases). It is known that Asian countries such as Japan, China, Korea, and Taiwan have relatively high severity of Hunter syndrome. The severity could vary. The next are five countries of the European Union: the United Kingdom, Spain, Italy, Germany, and France. The data available for now is known as dated back to 2017, not later. For those days, Germany had the most frequency of identified cases (83 people) followed by the United Kingdom (68 cases).

Genetical analysis of the GALNS gene for 13 affected children with clinical manifestations of Morquio syndrome resulted in the following nine mutations: c. 1144C>G (p. Leu382Val), c. 1265A-G (p. Gln422Arg), c. 463G-T (p. Gly155Cys), c. 1018G-T (p. Gly340Cys), c. 157G>A (p. Gly53Arg), c. 553C>T (p. Pro185Ser), c. 443A>G (p. His148Arg), c. 1283A>G (p. Gln428Arg), c. 439T>A (p. Trp147Arg). All nine GALNS gene mutations had missense mutations. The clinical variety of Morquio syndrome in patients from the Azerbaijan Republic could be explained by the GALNS gene mutation variety. In one patient, the GLBI gene was identified with its mutation c. 176G>A (p. Arg59His).

At the same time, we consulted and analyzed genetically 41 people with heterozygous carriages: MPS I-3 people, MPS II-12 people, MPS IV-26 people, relatively. One sibling was found to have a GALNS gene mutation: c. 463G-T (p.Gly155Cys) in the homozygous state (MPS IVA).

Our studies revealed gene level one mutation type - missense mutation/nonsense mutation in all affected children with MPS IVA and MPS IVB, that was the most spread mutation types. F.Kubaski et al., 2020 found that in genetical studies of patients with MPSI and MPSII syndromes in both genes: GALNS и GLB1 missense mutation/nonsense mutation type prevailed as 74.4% and 76%, relatively. The authors at that time examined 556 cases. The second mutation type for MPS IV both types was large deletion/large insertion 11.5% and 15.4%, relatively. Small deletion/small insertion takes the third position: 9.8% and 7.3%.

GALNS mutations' heterozygosity explains the vast clinical variability of MPS IVA. More than 300 mutations of the gene are identified and described, they are as follows: 78.4% are linked with missense mutations, 9.2% with small deletions, 5.0% with nonsense mutations, 2.4% with large deletions, 1.6% with insertions, small and large deletions, and transversions (Hendriksz, C. J. et al., 2015). The incidence of Morquio syndrome in different populations varies. When screening infants in Sweden and Japan between 1982 and 2009, Khan et al. (2017) discovered and diagnosed 469 affected patients with MPS of all forms, resulting in a frequency of 1.5:100,000 live newborns. MPS II accounted for 55% of them (0.8:100 000). MPS I and MPS II were shown to occur 15% and 10% of the time, respectively. In Sweden, retrospective epidemiological analysis was carried out for a period of 34 years, where genetic analyses of 41 patients were run. 12% of patients had got MPS I diagnosis, and 24% had MPS IV. In populations of Eastern Asia, Germany, Northern Ireland, Portugal and the Netherlands, MPS II prevailed highly up to 50%. It should be mentioned that in the above enumerated countries, other MPS types were also widespread. Differing from those said countries epidemiological data in Turkey showed quite a distinguished picture. 339 affected people with MPS diagnoses were distributed in the following order: MPS I -7.79%, MPS II - 14.29%, MPS III - 28.57%, MPS IV - 28.57%, MPS VI - 18.48%, and MPS VII - 1.29%. In Turks residing in Germany two types of MPS were found: MPS IIIB -33% and MPS IV -22. There were screenings of live newborns in the

USA for 20 years, and the frequency consisted of 0.98:100 000. Around 2.67 affected kids in every million newborns. The frequency of MPS I, MPS II and MPS III prevailed (0,26:100 000 and 0,70-0,71). Frequency of MPS IV, MPS VI and MPS VII were lower - 0.14, 0.04 and 0.02, relatively, i.e. per 100,000 live newborns (Church et al., 2013; Chen et al., 2016; Atçeken et al., 2016; Khan. et al., 2017; Caciotti et al., 2018; Puckett 2021; Zanetti et al., 2021).

## CONCLUSION

Hence, when medical genetical consultation of affected patients suspicious of lysosomal storage diseases, especially mucopolysaccharidoses, we for the first time in the Azerbaijan population identified and genetically studied 19 affected patients and 54 of their family members. One index patient suspicious with Hurler syndrome (MPS I) was identified missense mutation of the IDUA gene (NP_000194,2: c. 1882C>T, p. Arg628Ter) in the homozygous state. Three mutations of the IDS gene were identified: two missense mutations 1106C>G (p. Asp358Leu), c.322T>G (p. Asp358Leu) and one deletion c.1215del (p. Leu*34406Phefs) in hemizygous. In patients with Morquio syndrome (MPS IVA), nine GALBS gene missense mutations were identified: c. 1144C>G (p. Leu382Val), c. 1265A-G (p. Gln422Arg), c. 463G-T (p. Gly155Cys), c. 1018 G-T (p. Gly340Cys), c. 157G>A (p. Gly53Arg), c. 553C>T (p. Pro185Ser), c. 443A>G (p. His148Arg), c. 1283A>G (p. Gln428Arg), c. 439T>A (p. Trp147Arg) and one missense mutation of the GLB1 gene - c. 176G-A (p. Arg59His) that was responsible for Morquio syndrome (MPS IVB). Identified missense mutations were in homozygous and double heterozygous (compound) states. When examining family members of affected index patients, we found 41 people with heterozygous carriage of genes: 3 people with IDUA gene (MPS I) carriage, 12 people with IDS gene (MPS II) carriage, 26 people with GALNS gene (MPS IVA) carriage. At the same time when examining family members, a sibling of an index patient with Morquio syndrome (MPS IVA) identified c. 463G-T (p. Gly155Cys) in a homozygous state.

Considering the reproductive age of parents, fetus prenatal diagnostics is being planned for the next pregnancies.

## REFERENCES

**Alizade S.A., Rasulov E.M.** (2923) Sanfilippo A syndrome genetic studies in the patient Azerbaijan Republic. *Khazar J. of Science and Technology*, **7(2):** 28-36.

**Atçeken N., Özgül R.K., Yücel Yilmaz D., Tokatli A., Coşkun T., Sivri H.S., Dursun A., Karaca M.** (2016) Evaluation and identification of IDUA gene mutations in Turkish patients with mucopolysaccharidosis type I. *Turk. J. Med. Sci*., **46(2):** 404-408; doi: 10.3906/sag-1411-160.

**Caciotti A., Tonin R., Mort M., Cooper D.N., Gasperini S., Rigoldi M., Parini R., Deodato F., Taurisano R., Sibilio M., Parenti G., Guerrini R., Morrone A.** (2018). Mis-splicing of the *GALNS* gene resulting from deep intronic mutations as a cause of Morquio A disease. *BMC Medical Genetics*, **19:** 183; doi: 10.1186/s12881-018-0694-6.

**Chen X., Qiu W., Ye J., Han L., Gu X., Zhang H.** (2016) Demographic characteristics and distribution of lysosomal storage disorder subtypes in Eastern China. *J. Hum. Genet.*, **61:** 345–349; doi: 10.1038/jhg.2015.155.

**Chien Y.H., Lee N.C., Chen P.W., Yeh H.Y., Gelb M.H., Chiu P.C., Chu S.Y., Lee C.H., Lee A.R., Hwu W.L.** (2020) Newborn screening for Morquio disease and other lysosomal storage diseases: Results from the 8-plex assay for 70,000 newborns. *Orphanet Journal of Rare Diseases*, **15:** 38; doi: 10.1186/s13023-020-1322-z.

**Church H., June P., Jessica R., Oliver P., Christine E., Wendy S., Karen T.** (2013) The incidence of mucopolysaccharidoses and related disorders in the Turkish population: A 3 year study. *Molecular Genetics and Metabolism,* **108 (2):** S30.

**Fenton-Navarro P., Perez-Campos E., Socorro Pina-Canseco S., Fenton-Navarro B.** (2017) Gaucher's disease and Hurler's syndrome in two first cousins *International Journal of Human Genetics*, **17(3):** 109-117; doi:

10.1080/09723757.2017.1365433.

**Filocamo M., Tomanin R., Bertola F., Morrone A.** (2018) Biochemical and molecular analysis in mucopolysaccharidoses: What a paediatrician must know. *Italian Journal of Pediatrics*, **44:** 129; doi: 10.1186/s13052-018-0553-2.

**Galimberti C., Madeo A., Di Rocco M., Fiumara A.** (2018) Mucopolysaccharidoses: Early diagnostic signs in infants and children. *Italian Journal of Pediatrics*, **44:** 133; doi: 10.1186/s13052-018-0550-5.

**Hendriksz C.J., Berger K.I., Giugliani R., Harmatz P., Kampmann C., Mackenzie W.G., Raiman J., Villarreal M.S., Savarirayan R.** (2015) International guidelines for the management and treatment of Morquio A syndrome. *American Journal of Medical Genetics Part A*, **167:** 11-25; doi: 10.1002/ajmg.a.36833.

**Khan S., Alméciga Díaz C.J., Sawamoto K., Mackenzie W.G., Theroux M.C., Pizarro C., Mason R.W., Orii T., Tomatsu S.** (2017) Mucopolysaccharidosis IVA and glycosaminoglycans. *Molecular Genetics and Metabolism*, **120:** 78-95; doi: 10.1016/j.ymgme.2016.11.007

**Kubaski F., de Oliveira Poswar F., Michelin-Tirelli K., Burin M.G., Rojas-Málaga D., Brusius-Facchin A.C., Leistner-Segal S., Giugliani R.** (2020) Diagnosis of Mucopolysaccharidoses. *Diagnostics (Basel)*, **10(3):** 172; doi: 10.3390/diagnostics10030172.

**Lin H.Y., Lin S.P., Chuang C.K., Niu D.M., Chen M.R., Tsai F.J., Chao M.C., Chiu P.C., Lin S.J., Tsai L.P., et al.** (2009) Incidence of the Mucopolysaccharidoses in Taiwan, 1984-2004. *Am. J. Med. Genet. Part. A.*, **149:** 960-964; doi: 10.1002/ajmg.a.32781.

**Martins A.M., Lindstrom K., Kyosen S.O., Munoz-Rojas M.V., Thibault N., Polgreen L.E.** (2018) Short stature as a presenting symptom of attenuated Mucopolysaccharidosis type I: case report and clinical insights. *BMC Endocr. Disord.*, **18:** 83: doi: 10.1186/s12902-018-0311-x.

**Noh T.K., Han J.S., Won C.H., Chang S., Choi J.H., Moon K.C., Lee M.W., Yang J.H., Soung J.H.** (2014) Characteristic "pebbling" skin eruption as a presenting sign of Hunter syndrome. *Int. J. Dermatol.*, **53:** e594-e596; doi: 10.1111/ijd.12206.

**Puckett Y., Mallorga-Hernández A., Montaño A.M.** (2021) Epidemiology of mucopolysaccharidoses (MPS) in United States: challenges and opportunities. *Orphanet J Rare Dis.*, **16(1):** 241; doi: 10.1186/s13023-021-01880-8

**Zanetti A., D'Avanzo F., AlSayed M., Brusius-Facchin A.C., Chien Y.H., Giugliani R., Izzo E., Kasper D.C., Lin H.Y., Lin S.P., Pollard L., Singh A., Tonin R., Wood T., Morrone A., Tomanin R.** (2021) Molecular basis of mucopolysaccharidosis IVA (Morquio A syndrome): A review and classification of *GALNS* gene variants and reporting of 68 novel variants. *Hum Mutat.*, **42(11):** 1384-1398; doi: 10.1002/humu.24270.

.

**ORCIDS:**

Sevda Alizada: https://orcid.org/0000-0002-7543-0094
Shirkhan Musayev: https://orcid.org/0000-0002-8308-7089
Elkhan Rasulov: https://orcid.org/0000-0003-1363-1648

*Journal of Life Sciences & Biomedicine, vol. 6(79), No 2, p. 120-125 (2024)*

# Biocomprehensive ecomonitoring of *Tilia cordata* Mill. to assess the quality of the urban environment

**Minara Hasanova[1*], Gulnar Aidarkhanova[2]**

[1]*Institute of Dendrology, Ministry of Science and Education of the Republic of Azerbaijan, Mardakan, 29 Sharg Str., Baku, Azerbaijan*
[2]*Saken Seifullin Kazakh Agrotechnical Research University, 62 Zhenis Ave., 010000, Astana, Kazakhstan*

[*]***For correspondence:*** *minare.hasanova@inbox.ru*

Received: September 1, 2024; Received in revised form: October 17, 2024; Accepted: November 26, 2024

**The paper presents the results of complex ecological studies of the urban environment on the reaction of *Tilia cordata* Mill. grown in the recreational zone of Astana. The authors studied the features of surface horizons of soils on their toxicity using tracer test-object *Raphanus sativus* and heavy metal pollution. The quality of the environment is assessed by bioindicator indicators of fluctuating asymmetry of the linden leaf.**

***Keywords:*** *Bioindication, phytotoxicity, heavy metals, fluctuating asymmetry, the quality of the environment*

## INTRODUCTION

Increasing anthropogenic impact on the natural and urban ecosystems leads to environmental degradation and reduces habitat quality. It is known that transportation vehicles and industry are the main sources of environmental pollution in major settlements. Among all environmental factors, soil cover is the main source of all pollutants. Toxic substances in soil are absorbed by plants and lead to a deterioration of their quality, reducing their function in the natural environment (Mamedov, Hasanova, 2016; Andrianjara et al., 2021). Fluctuating asymmetry of the linden leaf is a recognized biological indicator parameter for assessing the quality of the natural environment (Kalaji et al., 2018).

Conducting complex ecological monitoring research for cities, such as Astana is the most actual, since the intensive urbanization process can lead to considerable negative environmental consequences if no action is taken to improve the state of the environment. In this regard, the main objective of the study was to conduct a comprehensive environmental monitoring of the urban environment to assess its quality. Biotesting and evaluation of phytotoxicity of soils, determination of heavy metal content in the soil surface, studying the response of *Tilia cordata* Mill. introduced in the park area of the city were the tasks of the research. *Tilia cordata* Mill. has a very difficult time adapting to the climatic conditions of the Absheron Peninsula, it was widely used in landscaping the city of Baku. At the same time, monitoring was carried out to protect the environment (Martynova et al., 2020).

*Tilia cordata* Mill. is a plant belonging to the *Malvaceae* family, genus *Tilia* L.

It is widespread in large areas of the Crimean Peninsula and the Caucasus Mountains. In its natural (wild) form, this tree species grows in the middle and southern latitudes of the European part of the Russian Federation, in mixed forests. In our country, this genus of trees is widespread in the mountainous regions of the eastern part of the Greater Caucasus and the Lesser Caucasus. This tree is most often found in different types of brown mountain forest soils (Hasanova et al., 2024).



https://doi.org/10.59849/2710-4915.2024.2.120
Available online 31 December 2024

## MATERIALS AND METHODS

*Tilia cordata* Mill. is a good ornamental plant, which is widely used in parks and squares of populated areas. We investigated the state of bioindicator parameters of trees and soils in the territories of the Institute of Dendrology of the Ministry of Sciences and Education of the Azerbaijan Republic and Footballers Square in Astana.

The ecological monitoring studies began in the summer of 2021.

*Tilia cordata* Mill. seeds from the city of Ganja (Azerbaijan) were introduced and propagated at the Institute of Dendrology of the Ministry of Sciences and Education of the Azerbaijan Republic. A number of scientific workers at the Institute studied the bioecological properties of this tree and recommended its use in the landscaping of Baku city. The appearance of the plants is shown in Figure 1.

The soil samples on the territory of the city park "Square of footballers", representing the lime avenue, *Tilia cordata Mill.* leaf samples served as material for research. Soil sampling was conducted by an envelope with an area of 200 $m^2$. Soil samples were collected from the surface horizon of 0-10 cm.

This tree species was propagated by seeds, stem cuttings, and cuttings.

**Fig. 1.** Flowers of *Tilia cordata* Mill.

Heavy metals in soil water extracts were determined by the conventional method of atomic absorption spectroscopy (Guidelines for laboratory…, 1995). The biological effects of environmental influences on organisms were evaluated by the fluctuating asymmetry parameter of *Tilia cordata* Mill. leaf. Sampling the leaves in the crown was made from leaves 30-50 from all tiers of each tree (Ajmone, Biasioli, 2010; Hasanova, 2021).

## RESULTS AND DISCUSSION

This tree species grows well under conifers and *Quercus* L. being a shade-tolerant tree species, it is also found under beech cover in the Azerbaijan forest. This indicates that the tree species has the ability to reproduce well in relatively humid and shady environments. The *Tilia cordata* Mill. is a tree genus of first-rate size. The height of this tree species is 30-35 meters, and the diameter of the trunk varies between 80-100 cm. It has a tent-shaped umbrella. It is a long-lived tree species. In natural conditions, it can live for 400-500 years (sometimes 1000 years).

When young, the bark is gray, but also thick and smooth. In old age, the bark darkens and becomes brown-gray, with longitudinal furrows. Pollinated by insects, mainly honey bees. It has oval or rounded heart-shaped leaves. In the territory of our country, *Tilia cordata* Mill. blooms in late June and early July (for about 10-15 days). This species of tree grown in the open field bears fruit after 8 years, and in forest conditions after 20 years. Fruits ripen in August-September. Its fruits are spherical or oval-shaped nuts, thin-skinned, with one or two seeds. The fruits of this tree species remain on the trees throughout the winter. It has a strong spindle root

that works deep into the soil. *Tilia cordata* Mill. is a frost-resistant tree species. So, this type of tree can withstand frost at - 48°C. In the first years of its life, it grows 5-10 cm per year. After 4-5 years, it grows by 30 cm per year. After 10 years, it grows 2-2.5 meters per year. At the age of 60, its growth rate slows down, after 130-150 years, it stops completely (Bayer et al., 2018; Urošević et al., 2019).

*Tilia cordata* Mill. alley was divided into a central crossroads in 2004 for the purpose of landscaping park areas in Astana. Small-leaved *Tilia cordata* Mill. is the basis of the range. Conducting visual observations, it was established that all the trees were growing moderately. The average length of the annual branch's growth was 0.17-0.23 m in 2020-2021. The compositions of different wood species such as white *Betula verrucosa* Erh., varieties of maple, willow were created alongside linden in the square. Individual specimens of conifers: *Pinus sylvestris* L., *Picea pungens* E. were planted.

Considering that a number of instrumental and biological methods of analysis are used to control environmental contamination, biological methods that more objectively reflect the ecological state of the system, in particular, the self-cleaning capacity of the soil, and its response to a particular stimulus were picked up by us. The biological method is highly effective in determining the overall phytotoxicity of the soil. It is simple in execution, operative, and allows for the quick determination of the total soil phytotoxicity. The principle of the method of biological indication is based on the relationship between the dose of the toxicant and the effect of its action on the test object. The main requirement for the test object is a high sensitivity to soil toxicants or their decay products. The coefficients of soil phytotoxicity computed from soil biotesting of linden alley by using Raphanus sativus are shown in Figure 2.

Studies of soil phytotoxicity have identified a number of characteristics. It is shown that in comparison with indicators of control samples, the deviation of length of radish roots grown in the soil recreational area is insignificant and equal to 18%. This indicates a low degree of phytotoxicity of the soil in a recreational zone.

The length of the roots of radish grown in suspension from the soil near the road was reduced by 3.8 mm compared to controls, indicating a pronounced degree of soil phytotoxicity near the main tracks. The deviation of root length of the test plants of the control parameter is set to 2.4 mm in the study of recreational zone soils. It is estimated as a slight excess of the benchmarks. A different picture is revealed for the site located in the depth of the square at a considerable distance from the road. Derivation from control indicators made 0.6 mm. In studying the phytotoxicity of soil taken from different zones of the investigated square found that indicators of soil phytotoxicity in the recreational zone changed in "the depth of the square near the mainline areas". The most typical characteristics of soil phytotoxicity – *Tilia cordata* Mill. alley corresponded to squares of the first row, at points 11,21,29, as shown in Figure 2.

The content of heavy metals in the soils of the square was studied in the surface horizons to a depth of 10 cm. The concentrations of elements such as Zn, Cu, Cd, Pb, Sr, Cr from aqueous extracts of soil were determined by us to establish parkland soil contamination with heavy metals. The research results are presented in Table 1.

Among the heavy metals, we determined Zn, Cu, Cd, Pb, Sr, Cr in soils, as they are considered the most toxic components of the natural environment.

Many of these elements are noted in the surface layer of soil samples "Square of footballers" in Astana. A considerable range of elements except Sr, registered in samples taken near the highway. It found that certain concentrations of all the elements Zn, Cu, Cd, Pb in the present conditions vary in very low limits which constitute 0.002-0.004 mg/kg.

Transportation emissions which are increasing in a geometrical progression due to the population growth and infrastructure development of the young capital are the main source of environmental contamination in Astana.

The absence of significant industrial enterprises in the city contributes to the slightest environmental pollution and subsequent escrow of heavy metals in land cover. As can be seen from the results of laboratory analyses, the cases of MPC excess for any of the studied elements haven't been revealed in the surveyed territories.

The organization of ecological monitoring will allow tracking of the growth dynamics of anthropogenic load on components of nature in the city by increasing the intensity of vehicular traffic.

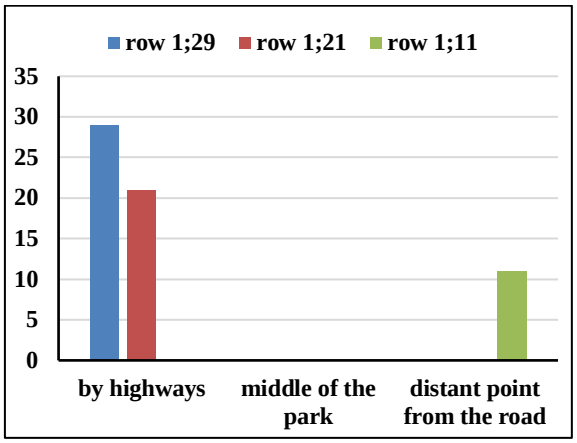


**Fig. 2.** Change in the coefficient of soil phytotoxicity in the "Square of footballers", %.

The fluctuating asymmetry of the linden leaf was determined to characterize the biological response of trees to environmental conditions. *Tilia cordata* Mill. is a perspective species for urban planting. It is relatively stable and has a high capacity for self-renewal. The study of morphometric parameters of leaves of woody plants in the streets with different movement intensities of vehicles revealed their specific variability. Results of scrutiny of fluctuating asymmetry of *Tilia cordata* Mill. leaves are shown in Table 2.

Ten-day observations of the biological condition of *Tilia cordata* Mill. trees showed that the square of necrosis increased towards the end of the summer (3rd decade of August) to 50% of the total square of leaves. Undoubtedly, this process is significantly affected by a change in the photosynthetic capacity of foliage. Morphologically, basically, as seen from the figures, the edge necrosis was observed in leaves. The number of damaged leaves increased from the bottom up. Supposedly the lower leaves are exposed to the gas emissions before the leaves of the upper tiers. Laboratory analysis showed that the level of transport pollution in the atmosphere affects the studied morphometric indicators of the linden state as the average size of the leaf blades.

Research of fluctuating asymmetry of the leaf blades showed that the asymmetry is an informative indicator of leaves: it was higher in stressed conditions than in an area remote from the highway at all studied plants. Certain parameters of the average value of fluctuating asymmetry for the group of trees near the highway amounted to 0.307. These same values for a group of trees from a remote highway section are 0.14. Response reactions of all tree crops are practically identical - values of fluctuating asymmetry of leaves of all the selected wood species are amplified. The studied indices of the mean value of fluctuating asymmetry of *Tilia cordata* Mill. can be used as test indicators of urban air pollution.

In general, a slight increase occurs in the average square of leaves in different habitat characteristics. The existing trend of reducing the size of woody plant leaves with an increase in the road transport load is confirmed by correlation analysis for linden. The asymmetry of the leaves is a more informative indicator: It varies depending on the location of the key areas in all the studied plants. The study of the bio-indicative properties by the quality of leaves allows us to note the linden as the most sensitive biological indicator. Analysis of the obtained experimental data shows that the small-leaved *Tilia cordata* Mill. reacts to anthropogenic pressure, the growth of which is associated with the intensification of car traffic.

**Table 1.** Heavy metal contamination of soils of city square territory in Astana

| Key areas | Zn, mg / kg | Cu, mg / kg | Cd, mg / kg | Pb, mg / kg | Sr, mg / l | Cr, mg / l |
|---|---|---|---|---|---|---|
| The standard content of heavy metals [10]. | 23.0 | 33.0 | 0.5 | 32.0 | | 6.0 |
| 1- near the highway territory | 0.002 | 0.004 | 0.003 | 0.003 | 0.0 | 0.112 |
| 2- the central part of the square | 0.0 | 0.0 | 0.0 | 0.0 | 0.06 | 0.0 |
| 3- the depth of the square, close to residential houses | 0.0 | 0.0 | 0.0 | 0.0 | 0.03 | 0.0 |

**Table 2.** Indicators of linear parameters of *Tilia cordata* Mill. leaves from different parts of the alley in modern ecological conditions Astana, cm

| Indicators | Near the motorway, number 1, point 29 | Away from the motorway number 1, point 11 |
|---|---|---|
| The width of the leaf blade halves | 0.307 | 0.102 |
| The length of the second leaf blade veins | 0.364 | 0.145 |
| The angle between the central and second veins of the leaf blade | 0.29 | 0.14 |
| The distance between the first and second veins of the leaf blade | 0.22 | 0.12 |

Thus, the complex ecological monitoring of *Tilia cordata* Mill. to assess the quality of the environment shows that the selected object confirms its high sensitivity to environmental changes. The study of this breed is promising because the linden proves resistant to various anthropogenic influences, has a high capacity for self-renewal, has high aesthetic qualities, acquiring a more compact shape when pruning the crown. Soil cover in places of *Tilia cordata* Mill. growing has a slight contamination by studied heavy metals. The cases of exceeding maximum permissible concentrations of certain elements Zn, Cu, Cd, Pb, Sr, Cr have not been identified. This feature of soil contamination of "Square of footballers" confirmed the integrated assessment of the degree of soil phytotoxicity in recreational areas. Indication index of *Tilia cordata* Mill. reaction on the fluctuating asymmetry characterizes the state of the trees as having a tendency to reduce the size of the leaves with an increase in the road transport load.

## CONCLUSIONS

The conducted studies allowed us to draw the following conclusions.

1. The results of the experiments showed that there were no cases of exceeding the maximum permissible concentrations of individual elements Zn, Cu, Cd, Pb, Sr, Cr in the soil samples of the linden alley.

2. Studies of the fluctuating asymmetry of leaf blades of *Tilia cordata* Mill. indicate that asymmetry is an informative indicator of leaves: under stressful conditions, it was higher than in the zone remote from the highway, for all the plants studied. The determined parameters of the average value of fluctuating asymmetry for a group of trees near the highway were 0.307. The same values for a group of trees from a site remote from the highway are 0.14, which is almost 2 times lower.

3. The parameters of fluctuating asymmetry of linden leaves obtained during monitoring will be comparable in subsequent years when analyzing bioindication indicators when assessing the state of the natural environment in urbanized areas (using the city of Astana as an example).

The study of bioindicator parameters of *Tilia cordata* Mill. in urban conditions showed that *Tilia cordata* Mill. is a promising species for landscaping parks and squares in populated areas.

The results of the research have shown that in the future it is necessary to develop a system of criteria differentiated by the composition of pollutants and levels of chronic pollution, which would allow us to reliably assess the levels of atmospheric air pollution by indicators of the state of plants and ecosystems, and vice versa. It will increase the efficiency of bio-indicative works and lay the scientific foundations for ecological forecasting and expertise.

## REFERENCES

**Ajmone Marsan F., Biasioli M.** (2010) Trace elements in soils of urban areas (in English), *Water Air Soil Pollut*., **213:** 121-143; doi: 10.1007/s11270-010-0372-6

**Andrianjara M., Bordenave-Jacquemin V., Roy C., Cabassa P., Federici D., Carmignac Y., Marcangeli G., Rouhan M., Renard F., Nold J.-C., Lata P., Genet S.** (2021) Planchais urban tree management: diversity of *Tilia* genus in streets and parks of Paris based on morphological and genetic characteristics. *Urban Green*., **66:** 127382; doi:

10.1016/j.ufug.2021.127382.

**Bayer D., Reischl A., Rötzer T., Pretzsch H.** (2018) Structural response of black locust (*Robinia pseudoacacia* L.) and small-leaved lime (*Tilia cordata* Mill.) to varying urban environments analyzed by terrestrial laser scanning: Implications for ecological function sand services. *Urban Forestry & Urban Green*, **35:** 129-138; doi:10.1016/j.ufug.

**Gahramanov Sh., Hasanova M.Y., Tagiyev M.M.** (2014) Monitoring of phytosanitary status of elm and linden plants in Goygol National Park. Within the framework of the "Year of Solidarity for the Green World", Republican scientific-practical conference on "Plant pests and their management under conditions of global climate change", Ganja: pp. 152-156 (in Azerbaijani).

**Guidelines for laboratory and practical classes in soil physics** (1995) For third-year students of the soil department, Comp. V.A.Korolev. Voronezh: 28 p. (in Azerbaijani)

**Hasanova M.Y.** (2021) Dendroflora of Hyrkan flora of Azerbaijan Republic and dendrochronological review of some species. Garden Science Magazine, 8(2): 43-55; doi: 10.35163/bagbahce.899831

**Hasanova M., Huseynova A., Guliyeva S., Badal-zade N., Taghiyev S.** (2024) The impact of climate change on the taxonomic composition of the Zagatala State Nature Reserve. *BIO Web Conf.*, **100:** 02025, p.1-7; doi: 10.1051/bioconf/202410002025

**Kalaji H.M., Račková L., Paganová V., Swoczyna T., Rusinowski S., Sitko K.** (2018) Can chlorophyll-a fluorescence parameters be used as bio-indicators to distinguish between drought and salinity stress in *Tilia cordata* Mill. *Environ. Exp. Bot.*, **152:** 149-157; doi: 10.1016/j.envexpbot.2017.11.001.

**Mamedov T.S., Hasanova M.Y.** (2016) Diversity of dendroflora of Azerbaijan Current problems of modern science, “Sputnik+” Publishing House LLC, 2 (87), p. 246-248. (in Russian)

**Martynova M., Sultanova R., Odintsov G., Sazgutdinova R., Khanova E.** (2020) Growth of *Tilia cordata* Mill. in urban forests. *South-East European Forestry*, **11:** 51-59.

**Urošević M.A., Jovanović G., Stević N., Deljanin I., Nikolić M., Tomašević M., Samson R.** (2019) Leaves of common urbantree species (*Aesculus hippocastanum, Acer platanoides, Betula pendula* and *Tilia cordata*) as a measure of particle and particle-bound pollution: a 4-year study. *Air Qual. Atmos. Health*, **12(9):** 1081-1090; doi: 10.1007/s11869-019-00724-6.X

**ORCIDS:**
**Minara Hasanova:** https://orcid.org/0000-0001-5222-9366
**Gulnar Aidarkhanova:** https://orcid.org/0000-0002-5108-8036