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Use of Mind Maps in the Teaching of Natural Sciences

Abstract

The characteristic and general aspects of teaching natural sciences in secondary general education schools have been studied. It has been noted that the most common feature of the natural sciences, which include chemistry, biology, physics, and geography, is their close connection and interrelation with natural phenomena. It has been shown that, as exact sciences, the natural sciences and the corresponding fields of study consist of both theoretical and practical components, and the similarity of their research methods and objects makes it possible to use the mind map method in the teaching of these subjects, including chemistry. It has been determined that the common aspects of the natural sciences, the similarity of research objects, and their methodological proximity indicate the necessity of a unified approach in their teaching. From this perspective, as in the process of teaching chemistry, the mutual integration of theoretical and practical components in biology, physics, and geography lessons is of great importance. Such an approach enables the integrative study of natural sciences, the establishment of interconnections between different scientific disciplines, and the correlation of knowledge with real life. This contributes to the development of students' logical, critical, and creative thinking, the formation of scientific reasoning, and the enhancement of their ability to analyze problems from multiple perspectives. The use of mind maps in teaching natural sciences creates conditions for the systematization of scientific concepts, the establishment of logical connections between topics, and the more visual, interactive, and sustainable assimilation of lessons.

Keywords: *didactics, mind map, natural sciences, visual, audial, kinesthetic, digital, education, upbringing*

Introduction

The issues related to the use of mind maps in teaching chemistry in secondary general education schools have been extensively discussed in the sources (Babayev & Babayeva, 2021), where it has been shown that the main principles of educational reform in our Republic are aimed at the formation and development of student-centered education and interactive learning. The theory of teaching and education (Babayeva & Babayev, 2020) — *didactics* — considers education as the result of teaching and teaching as the means leading to education. From this perspective, the teaching method should be chosen correctly so that its result — that is, the effectiveness of the education provided to students — is high. In other words, what matters is not how much we know, but how much we are able to convey to others (Mammadova, 2017). Despite the diversity of forms and methods applied in the education system, the most important factor for students is their ability to retain what they read and learn, and to increase their learning efficiency.

Throughout the history of humanity, among the various types of diagrams and maps used for different purposes over millennia, mind maps occupy a special place due to their distinctive method

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of creation and direction of use. Sometimes referred to as "the key to memory," mind maps are valuable because their creation and use develop imagination and creative thinking, strengthen memory, and ensure the joint activity and harmony of the brain hemispheres. For these reasons, they serve as both a learning and teaching tool suitable for use in almost all areas of human activity, including the educational process (Babayeva, 2022).

It should be noted that at the end of each topic or a specific completed section taught in chemistry lessons in secondary general education schools, a corresponding mind map is constructed. The constructed mind map essentially serves as an effective repetition of the lesson. The initiators of the mind map method have also approached it as a pedagogical aid and an engaging motivational tool for students in mapping the topics covered. Through this method, learning does not lag behind traditional and interactive teaching methods based on the use of textbooks and teaching aids — in some cases, it even surpasses them. This is because the material being studied is divided into smaller portions through branching using main and derived keywords in the relevant mind map, allowing students to easily verify the correctness of each question and its corresponding answer.

In general education schools, the existence of a specific "language of chemistry," consisting of chemical symbolism, terminology, and nomenclature, distinguishes the chemistry subject from all other disciplines (Abishov, 2022). At the same time, the science of chemistry has the broadest connections with all other scientific fields. Thus, in research related both to living organisms and to the inorganic world, the symbolic language of chemistry and its applications are widely used. Another characteristic feature is that the written form of the chemical language is more significant and richer than its oral form.

In secondary general education schools, the language of chemistry is a didactically developed version adapted to the goals and content of instruction, taking into account students' age characteristics and psychological factors. It is aimed at mastering the school chemistry course, as well as fostering students' development and education. Unlike the scientific language, the school chemistry language is simpler, more comprehensible for students, free from complex linguistic structures, and features simplified terminology and nomenclature.

The language of chemistry is applied at all stages of chemistry teaching and research.

Research

The purpose of the present study is to explore the didactic potential of using the mind map method in the teaching of natural sciences in secondary schools and to identify its characteristic features. It is known that didactics — a specialized branch of pedagogy — examines the most important problems of teaching and learning, determines the optimal boundaries of students' education and upbringing by taking into account the achievements of scientific and technological progress as well as students' age characteristics, and scientifically substantiates the content and objectives of the teaching process.

In addition, didactics defines, in accordance with the intended goals, the forms and methods of teaching, the principles of selecting theoretical and practical lessons, and the relevant tasks that need to be addressed in the process of acquiring the knowledge and skills necessary for future development. At the same time, it is required to demonstrate the transition in the teaching process from learning the subject to generalizing it. In this process, students' individual characteristics must be taken into account, and the teaching process should be made engaging and dynamic.

General Characteristics of Natural Sciences and Subjects

The fields of study that examine the natural factors influencing human beings from the external environment are called natural sciences, while the corresponding school disciplines are referred to as natural science subjects. Everything that surrounds us is related in one way or another to the natural sciences. The foundation of natural sciences is their connection and interrelation with natural phenomena. Over time, the natural sciences have developed into distinct scientific directions.

The basis of the development of every process or phenomenon lies in the unity and struggle of contradictions (opposites). This concept also applies to modern natural science. In natural sciences, two mutually opposing yet unified tendencies are characteristic — one represents analyticity in the process of development, and the other represents syntheticity. Through the analytical approach, new

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branches of science and new laws are discovered. The objects of such research become more specific, and specialized scientific methods are applied.

In secondary general education schools, natural science subjects include biology, chemistry, physics, and geography. Geography is classified as a natural science subject because its object of study is the Earth — the habitat of all living beings, including humans. The branch of physical geography develops and expands by relying on the laws discovered by other natural sciences.

Physics belongs to the natural sciences and studies the quantitative regularities of natural phenomena at both macroscopic and microscopic levels. The laws of physics, based on experimentally obtained facts and certain quantitative relationships, are expressed in the language of mathematics. Purely chemical qualitative and quantitative analysis methods can no longer fully meet the increasing demands of modern science, technology, and industry. Therefore, the use of physical research methods based on deeper structural levels of matter is of decisive importance. The research objects of physics are diverse, including solid-state physics, atomic physics, plasma physics, nuclear physics, and others.

The next natural science is chemistry. Chemistry is important for humanity because it enables the production of essential materials and products for society from natural raw resources through chemical transformations.

The principal natural science is biology. Biology is the science of living organisms, and their main characteristics are growth and development, movement, response to stimuli, reproduction, and metabolism (nutrition, respiration, excretion). Biology, which studies living organisms, is divided into various fields such as botany, zoology, mycology, and others.

Various methods — primarily observation, experimentation, and measurement — are used to study living organisms:

- Observation is based on studying an object or phenomenon through the senses. It can be conducted both in natural and laboratory conditions, often using various instruments, devices, and equipment.
- The experimental method is used to test, confirm, or refute hypotheses formulated as a result of observations.
- Measurement is applied in many cases during the performance of observations and experiments.

Thus, by applying these research methods, the researcher succeeds in obtaining certain scientific knowledge about the object or phenomenon under study.

The discussions conducted show that the natural sciences study the world from a materialistic point of view and require society to approach nature with respect for its laws. Naturalism is a system based on studying and utilizing the laws of nature without applying human-made laws to natural processes. The emergence of the natural sciences is the result of a philosophical approach to scientific research. Since the methodology of mathematics differs significantly from that of the natural sciences, it is not classified among them. Mathematics is considered the foundation or basis of certain natural sciences.

In the natural sciences, scientific results are generally based on objectivity and precision, taking experimental and observational outcomes as their foundation. The natural sciences are not static; they are constantly undergoing processes of refinement and clarification.

In all natural sciences, a mathematical apparatus is used to describe observed natural phenomena. The natural sciences require the precise representation and formulation of natural laws. In this way, explanations of natural phenomena are expressed in the form of mathematical equations. Subsequently, by means of these mathematical formulas, any hypothesis can be re-examined, refined, or supplemented.

The conducted discussions make it possible to distinguish a number of common or similar characteristics among the natural sciences (subjects) under consideration:

1. Similarity or identity of research methods.
2. The inclusion of all natural sciences among the exact sciences.
3. Similarity or identity of research objects.

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4. The existence of an original (written) language specific to each individual science or subject.
5. The structure of each science (or subject) consisting of both theoretical and practical components.

Taking into account these common features and several other factors, it can be confirmed that, alongside chemistry, the mind map method can also be successfully applied in the teaching of other natural sciences in secondary general education schools. As in other subjects, one of the most important aspects in teaching natural sciences is the development of students' ability to correctly comprehend and express the knowledge they acquire.

When differences in how individuals perceive and process information are considered in the teaching process, there arises a necessity to implement instructional strategies that support such individuality. From this perspective, the mind map method can serve as an effective tool to enhance the learning potential of students who possess diverse representational systems.

Representational Systems

In the teaching process, the dominant representational system of a student directly determines his or her learning style. Representational systems in education define how an individual symbolically interprets the surrounding world. The same external perceptions of the world can evoke very different reactions in different people. What makes one person happy may make another sad. This is because every individual filters the information that enters the brain through the lens of their past experiences, beliefs, and values. At this point, the information received from the external environment may also generate internal sensations. Through these internal sensations (representational systems), a person's experiences and thoughts can change and be influenced.

People usually make decisions because they seem logical to them and believe that their decisions are based on reason. However, in reality, these decisions are not necessarily based on logic; they are made because they make sense to the person in visual (sight), auditory (hearing), kinesthetic (feeling), or digital (analytical) terms. Later, individuals attempt to justify these decisions logically to others. In the field of personal development (NLP), these sensations are referred to as "representational systems." Every person has a representational system that predominates in the way they perceive and internalize information (Tokur, 2011).

Visual (Sight-Based) Learning

Visual learners understand information more effectively through images, graphics, colors, and diagrams. Their memory is built upon visual associations. Their learning style:

- It is beneficial to present information using colors, diagrams, and maps.
- The teacher's gestures and writings on the board help them learn.
- Looking at pictures and diagrams is more effective for them than reading text.
- The student "sees" and "recalls" information in their mind.

Auditory (Sound-Based) Learning

Auditory learners retain information more easily when they hear it. They prefer to learn through sound, rhythm, and tone. Their learning style:

- Listening to the teacher's speech, engaging in discussions, and sharing ideas in groups enhance their learning.
- Repeating information aloud is essential for memorization.
- Learning through rhythm, music, or poetry is highly effective.

Kinesthetic (Movement and Sensation-Based) Learning

Kinesthetic learners acquire knowledge through movement, touch, experience, and feeling. Their learning style:

- They learn by touching objects and working with models.
- Role-playing, conducting experiments, and engaging in active learning activities are important for them.
- Sitting still for long periods makes learning difficult for them.

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Logical and Analytical (Digital) Learning

Analytical learners learn through logic, analysis, and systematic thinking. They internalize information not through feelings, but by understanding and identifying cause-and-effect relationships. Their learning style:

- They prefer to structure information, create plans, and explain it in logical sequence.
- "Why?" and "How?" questions are essential for them.
- Justification and evidence for information are important to them (Adler, 2005).

Every individual possesses all representational systems; however, during perception and assimilation of information, the mind automatically processes it according to the person's individual characteristics, prioritizing visual, auditory, kinesthetic, and digital systems in a specific order, and this plays a crucial role in shaping an individual's learning style. Pedagogical experience shows that different learning types demonstrate specific cognitive and behavioral patterns in processing information. Digital learners process information logically and draw analytical conclusions immediately after hearing it, visual learners prefer to organize information in written form before expressing their thoughts, kinesthetic learners respond more emotionally, and auditory learners tend to request that the information be repeated aloud.

Mind maps are a universal learning tool in the pedagogical process that integrate all representational systems. They help develop a student's logical, critical, and creative thinking, as well as their imagination, while increasing lesson productivity. Mind maps can also be successfully used in the teaching of natural sciences.

Representational systems	**Correspondence to a mind map**	**Conclusion**
Visual	Images, colors, symbols, and branches strengthen visual memory and facilitate the assimilation of information.	The student learns the information by "seeing" it.
Auditory	During discussion and presentation, the student both listens and assimilates knowledge by comparing it with other ideas.	The student learns the information by "listening" to it.
Kinesthetic	The student draws the map, writes, makes connections, and learns the topic by feeling it through touch and movement.	The student learns the information by "feeling" it.
Digital	In a mind map, cause-and-effect relationships between concepts are visible, and information is perceived in a structured form.	The student learns the information by "understanding" it.

Such an approach creates conditions for the integrative study of natural sciences and for the development of students' logical, critical, and creative thinking. The use of mind maps in teaching natural sciences ensures a deeper understanding of scientific concepts and makes the learning process more visual, interactive, and continuous.

The main principles of natural sciences involve informed and developmental functions based on relevant observation, experimentation, and measurement. Selecting the main concepts and laws reduces the memorization load of the taught material, saves time, and implements the principle of small amounts of material providing more knowledge.

In general education schools, the teaching of natural sciences also demonstrates ways to master knowledge systematically. Through mental activity, students have the opportunity to rediscover the knowledge they acquire and experience the joy of learning. With purposeful mental activity, recall and comprehension lead to the creation of new scientific ideas and allow for various investigations.

Recent scientific achievements have shown that many natural phenomena are understood more clearly when studied within the framework of interconnected natural sciences rather than a single science. For example, many biological processes in the human body, in living organisms, and in

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nature are based on chemical processes. Therefore, when explaining relevant topics, both chemistry and biology information is presented together so that students can understand them based on logic and experimental results.

Such integrative teaching both facilitates the establishment of interdisciplinary connections and allows students to understand natural sciences more comprehensively and systematically.

It should be noted that students' ability to overcome difficulties and the development of their thinking largely depend on their comprehension and understanding skills. Weak reading and comprehension skills in schools create difficulties in understanding and grasping chemistry topics, which students often carry with them to higher education. Chemistry, being a challenging subject, requires a strong foundation in reading and the language of chemistry. Therefore, improving achievements in chemistry at both secondary and higher education levels necessitates an increase in students' reading habits. Learners who are skilled at working with texts in their native language can also understand and analyze chemical problems more effectively (Alder & Berly, 2001).

It has been shown that the level of students' reading and comprehension skills directly correlates with their performance in chemistry. In secondary schools and during university entrance exams, where knowledge is often evaluated through tests, weaknesses in writing, reading, and comprehension continue to manifest in later stages of education and professional life (college, university, workplace, etc.). One source of these weaknesses is the influence of social networks, computers, mobile phones, and incorrectly written captions displayed on some private TV channels. Modern youth often spend a large portion of their free time on unsupervised mobile phone calls and messaging. Errors in writing, reading, and communication within their immediate environment, including family interactions, often become habitual and are carried over into university classrooms and workplaces, making correction more difficult.

However, writing, speech, and comprehension difficulties are usually addressed to some extent in university settings before graduates carry them into workplaces. In our view, effective measures include teaching *Business and Academic Communication in Azerbaijani* in most bachelor programs, conducting written exams and relevant colloquiums for professional courses, and ensuring interactive teaching methods to develop oral communication skills, in accordance with educational reform requirements. In these efforts, teachers must also demonstrate civic responsibility.

Experience in teaching chemistry at universities has shown that mastery of the language of chemistry first requires proficiency in Azerbaijani, the language in which the subject is taught and studied. This principle applies to all subjects, particularly natural sciences, and to the languages in which the subjects are learned.

Conclusion

Considering that natural sciences and their respective fields (chemistry, biology, physics, geography) share several common characteristics — such as being exact sciences, having identical research objects, and consisting of both theoretical and experimental components — and, most importantly, that they are closely related to and interconnected with natural phenomena, it can be concluded that mind maps, successfully used in teaching chemistry, can also be applied effectively in the teaching of other natural sciences.

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Chemiluminescence Study of the Formation of Protein Radicals Under the Influence of Ultraviolet-B Rays

Abstract

The presented work reviews the molecular mechanisms of the formation of reactive oxygen species (ROS) in protein solutions exposed to ultraviolet-B (UV-B) (mainly UV-B: 280–315 nm) radiation, the role of proteins in their formation, and the biological significance of these processes. It is known that ROS species, in turn, cause the formation of long-lived protein radicals (LLPRs). The amount of LLPRs formed in human serum albumin protein upon exposure to UV-B (1.2×10^2, 2.4×10^2, 3.6×10^2, and 4.8×10^2 erg/mm²) irradiation was studied by the chemiluminescence (XL) method. It was observed that the intensity of XL varies depending on the irradiation dose. The introduction of antioxidants into the system leads to a weakening of the effect of UV radiation. Thus, inosine neutralizes long-lived protein radicals more effectively than natural antioxidants. In our opinion, since ROS play a signaling and regulatory role in biological studies, their formation and LLPRs play an important role in the adaptation of living systems to stress factors.

Keywords: *Long-lived protein radicals, oxidative stress, reactive oxygen species, UV-B radiation, chemiluminescence*

Introduction

Free radicals, defined as atoms or molecules containing one or more unpaired electrons, are highly chemically reactive species capable of inducing destructive effects on molecular components within biological systems (Ayala et al., 2014; Kowalczyk, Sulejczak, et al., 2021; Mandal et al., 2022). Reactive oxygen species (ROS) and reactive nitrogen species (RNS) can originate from endogenous metabolic processes or be induced by exogenous stressors such as ionizing radiation, ultraviolet radiation, environmental pollutants, cigarette smoke, heavy metals, and certain pharmacological agents (Kocharli & Hummatova, 2020). During normal cellular respiration, approximately 1–2% of molecular oxygen is converted into ROS. When the concentration of reactive oxygen species exceeds the buffering capacity of antioxidant defense systems, cascade reactions can occur, resulting in lipid peroxidation, protein denaturation, and DNA damage (Lobo et al., 2010; Ayala et al., 2014; Zorov et al., 2014; Kowalczyk, Sulejczak, et al., 2021).

Although UV-B radiation constitutes a minor fraction of solar radiation, it exhibits strong photobiological activity. It can induce the formation of pyrimidine dimers in DNA and structural alterations in proteins. Proteins, due to their abundance in biological systems, are particularly vulnerable to oxidative stress and become primary targets for radical-mediated damage. Although UV-B radiation constitutes a minor fraction of solar radiation, it exhibits strong photobiological activity. It can induce the formation of pyrimidine dimers in DNA and structural alterations in proteins. Proteins, due to their abundance in biological systems, are particularly vulnerable to

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oxidative stress and become primary targets for radical-mediated damage (Rastogi, Kumar, et al., 2010; Kocharli & Hummatova, 2019).

Free radicals and other oxidizing agents are involved in various physiological processes and also contribute to the development of diseases. Such modifications are not only implicated in the loss of protein function but also play a critical role in the pathogenesis of aging and degenerative diseases. Protein oxidation, driven by reactive radicals, disrupts cellular signaling and impairs homeostasis (Alugoju et al., 2014; Bin et al., 2017; Jomova, Raptova & Alomar, 2023; Chandimali, Bak, et al., 2025).

Upon exposure to UV-B radiation, ROS species such as singlet oxygen ($^1O_2$) and superoxide anion ($\bullet O_2^-$) are formed, leading to site-specific post-translational modifications, particularly at cysteine and methionine residues. Cysteine residues, as one of the primary targets of ROS, undergo selective oxidation that alters protein structure and function and promotes the formation of various secondary products (Brosnan et al., 2006; Alugoju et al., 2014; Rajesh et al., 2010).

ROS produced in bovine serum albumin and gamma-globulin solutions via laser irradiation lead to the formation of LLPRs with a half-life of approximately ~4 hours. LLPRs generated by laser irradiation last for a long time or several hours and result in the formation of ROS — hydrogen peroxide, hydroxyl, and superoxide radicals (Vladimir et al., 2017).

Studies have shown that LLPRs can be generated not only by ionizing radiation but also by UV irradiation, peroxynitrite ($ONOO^-$), uranyl ions (UO_2^{2+}), decomposition of H_2O_2 by peroxidases, and hyperthermia (Michael, 2005; Gudkov et al., 2010). Using highly specific techniques such as electron spin resonance (ESR) spectroscopy and chemiluminescence, the lifetime of these radicals has been revealed to exceed 20 hours (Yoshimura et al., 1993). Furthermore, these protein radicals may interact with other biomolecules, particularly DNA, thereby contributing to genotoxic damage (Bruskov, Popova, et al., 2014).

Materials and Methods

Albumin protein solution was selected as the research object, and the formation of LLPRs was measured using a quantum chemiluminescence detector. Ascorbic acid and inosine were used as natural antioxidants in the experiments. The chemiluminescence method, a highly sensitive technique for detecting energy emission during radical reactions, was employed (Kocharli & Hummatova, 2024). UV-B irradiation was performed using a PRK-4 mercury lamp, and protein samples were exposed to radiation doses of 1.2×10^2, 2.4×10^2, 3.6×10^2, and 4.8×10^2 erg/mm².

Results and Discussion

It has been established that long-lived protein radicals can be a source of reactive oxygen species and long-term oxidative stress in biological systems and can transmit oxidative damage to other molecules, including DNA. Long-lived protein radicals can be measured immediately using electron spin resonance (ESR) spectroscopy. However, its low sensitivity often necessitates the use of high radiation doses (1–5 kGy) when employing the chemiluminescence method (Luxford, 1999; Gudkov et al., 2007). The CL method, which is a sensitive method for detecting free radical reactions, releases energy in the form of light quanta during the interaction of radicals (Kocharli & Hummatova, 2020).

In this study, we assessed the LLPR formation by measuring the chemiluminescence of protein solutions exposed to UV-B radiation using a highly sensitive chemiluminescence method. It is known that some natural antioxidants, such as guanosine, inosine, and ascorbic acid, can neutralize the oxidative stress caused by the oxidation of free radicals. Model proteins, including egg albumin, bovine serum albumin, HSA, immunoglobulin G, and histone H1, are well-established systems for studying LLPR generation (Gudkov et al., 2010).

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Figure 1. Scheme of the formation of Long-Lived Protein Radicals during exposure to UV-B rays.

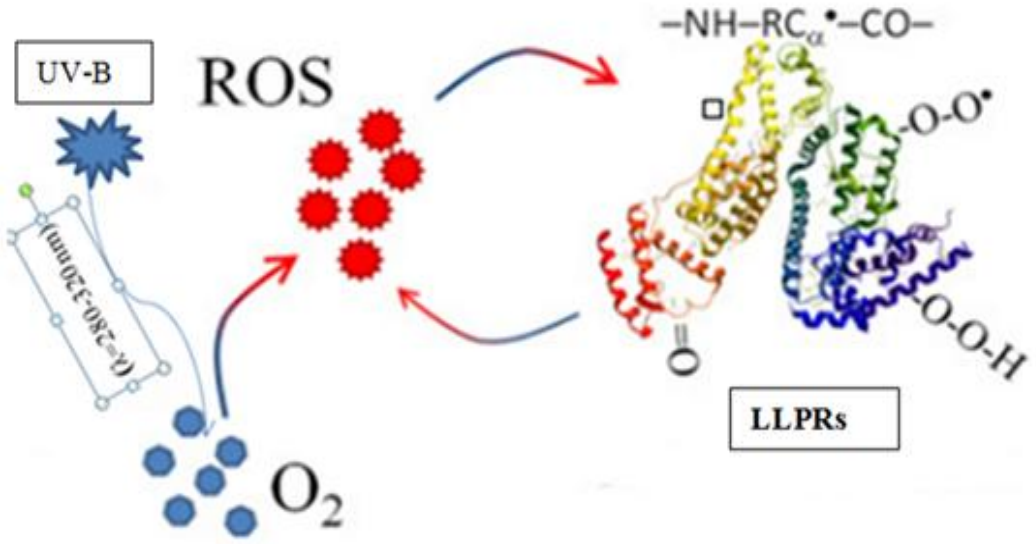
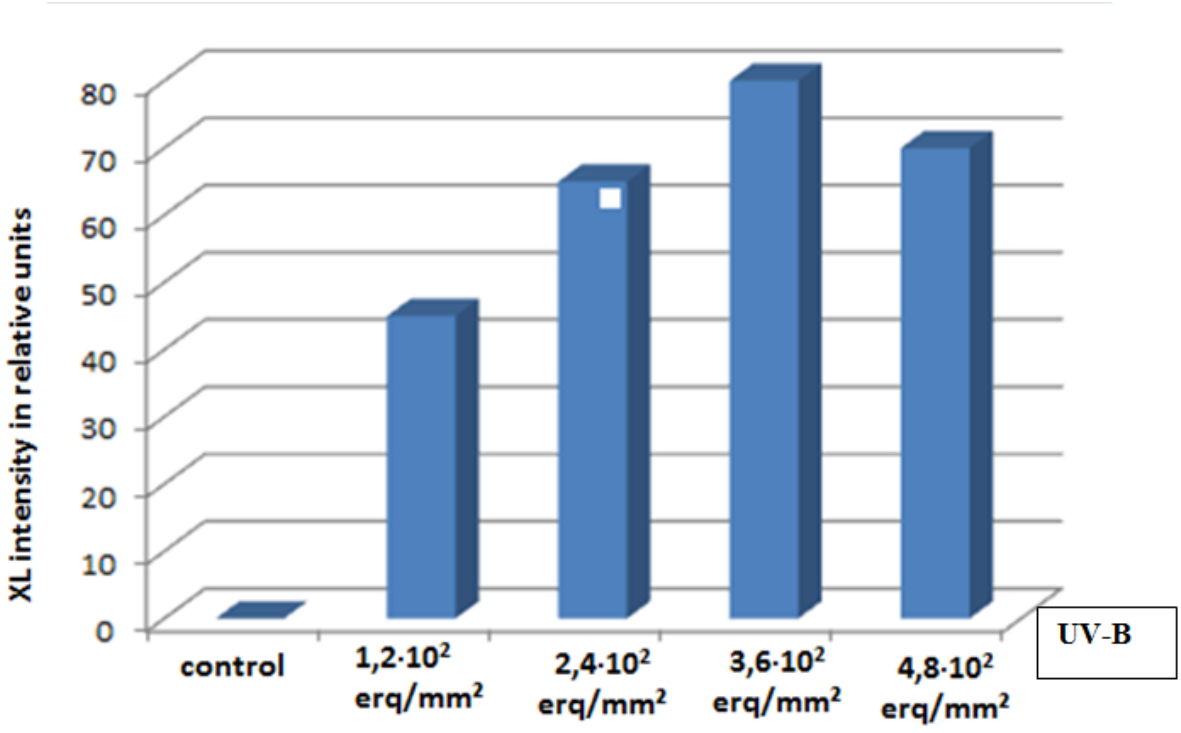


Figure 2. Changes in chemiluminescence (CL) intensity in human serum albumin solution (1%) under different doses of UV-B radiation (1.2×10² – 4.8×10² erg/mm²).



As shown in Figure 2, an increase in chemiluminescence intensity was observed in albumin solutions exposed to UV-B radiation at doses ranging from $1{,}2 \cdot 10^2$-$3{,}6 \cdot 10^2$ erg/mm². As shown in Figure 2, an increase in chemiluminescence (CL) intensity was observed in albumin solutions exposed to UV-B radiation at doses ranging from 1,2×10² to 3,6×10² erg/mm². Thus, the maximum value of the CL intensity was observed in the albumin solution exposed to a dose of 3,6×10² erg/mm² UV-B radiation. However, at a higher dose of 4,8×10² erg/mm², a decrease in CL intensity was noted.

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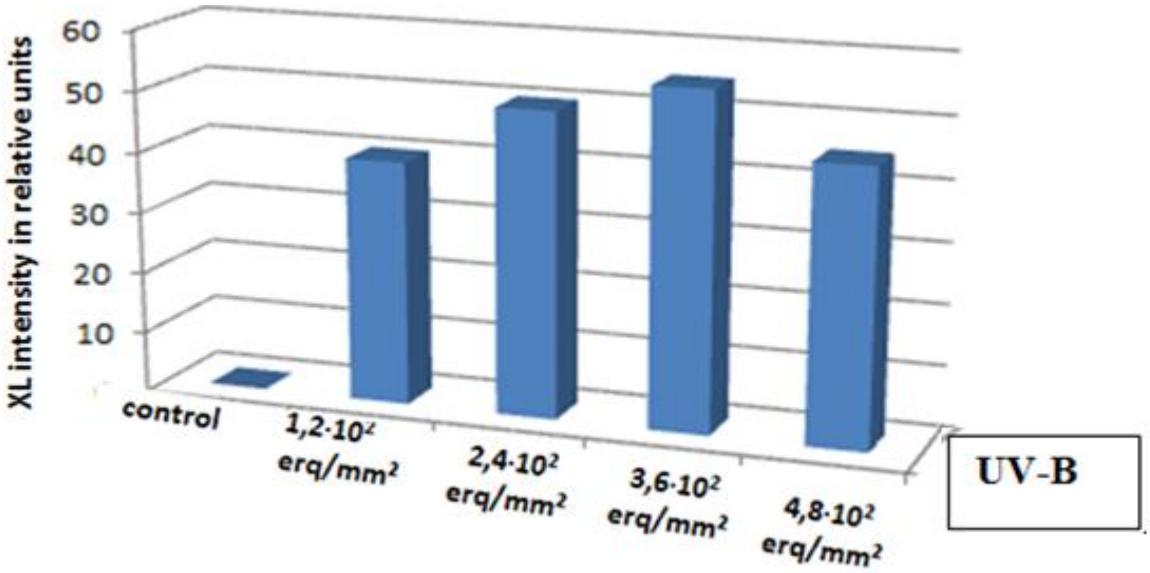
We propose that the changes in the CL induction curve during UV-B exposure are associated with the formation of long-lived protein radicals (LLPRs) generated in vitro during radiation exposure.

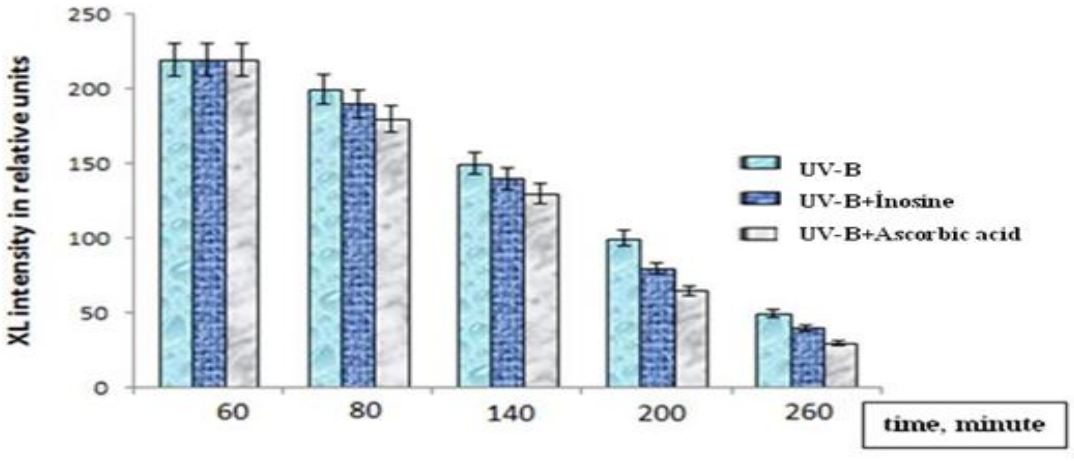
As shown in Figure 3, after exposure of the albumin solution to inosine (1×10-4 M) resulted in decreased CL intensity following irradiation with UV-B at doses ranging from $1{,}2\times10^2$ to $3{,}6\times10^2$ erg/mm² (Davies, 2005).

Figure 3. Effect of inosine (1×10^{-4} M) on the amount of LLPRs formed upon UV-B radiation of human serum albumin protein (1%).



The most significant reduction occurred at a high dose of the stress factor, which is due to the neutralizing effect of inosine on LLPRs formed in human serum albumin (Yoshimura, Matsuno & Miyazaki, 1993).

Similar results were obtained in experiments with the effect of ascorbic acid (1×10^{-3} M). Figure 4 illustrates the neutralization of LLPRs by antioxidants such as ascorbic acid and inosine. Based on these findings, we further examined the concentration-dependent effects of inosine at different concentrations on the elimination of LLPRs formed in human serum albumin upon UV-B exposure. Following the addition of inosine (riboxin) and ascorbic acid to human serum albumin, a significant reduction in long-lived protein radicals (LLPRs) was observed within 20 minutes. After 200 minutes of incubation, inosine reduced the LLPR content by approximately 2.5-fold, while ascorbic acid achieved a 1.5-fold reduction (Phaniendra, Jestadi & Periyasamy, 2015).



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Conclusion

These results indicate that inosine is more effective than ascorbic acid in neutralizing long-lived protein radicals among the natural antioxidants tested. It is assumed that the findings of this study may contribute to a better understanding of the mechanism of highly reactive molecules and their role as mediators of oxidative modifications of cellular components.

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Species Diversity of the Family Cyprinidae in the Middle and Southern Caspian Sea

Abstract

The species diversity of the *Cyprinidae* family distributed in the Middle and Southern Caspian Sea is of particular importance for the conservation of the ichthyological biodiversity of the region. The research has revealed that several genera and species of the *Cyprinidae* family are widely distributed in this area. Among them, kutum (*Rutilus frisii kutum*), common carp (*Cyprinus carpio*), bream (*Abramis brama orientalis*), crucian carp (*Carassius carassius*), roach (*Rutilus rutilus caspicus*), and other representatives are dominant. The formation of species composition is significantly influenced by ecological factors such as water temperature, salinity, food resources, and anthropogenic impacts. In particular, industrial pollution, regulation of water resources, and fishing pressure have led to a decline in the population density of several species. Nevertheless, some adaptive species have managed to preserve their ranges by adjusting to new environmental conditions. The research results indicate that in order to conserve the biodiversity of cyprinids in the Middle and Southern Caspian Sea, it is essential to conduct modern ecological monitoring, restore natural spawning grounds, and apply scientifically based methods in fish stock management.

Keywords: *Middle and Southern Caspian Sea, Cyprinidae, fish, species, biodiversity*

Introduction

The Caspian Sea is considered the largest lake on Earth and represents a closed water basin located in a vast continental depression. The total length of its coastline, including islands, is approximately 7,000 km. Along its 6,500–6,700 km shore, five countries are located: the Republic of Azerbaijan, the Republic of Kazakhstan, the Islamic Republic of Iran, the Russian Federation, and Turkmenistan. The length of the coastline in these countries is as follows: Azerbaijan – 825 km, Kazakhstan – 2,320 km, Iran – 900 km, Russia – 695 km, and Turkmenistan – 1,200 km.

The Caspian extends about 1,200 km in the meridional direction, with an average width of 310 km. Its widest part reaches 435 km, while the narrowest is 195 km. At this level, the total surface area is 392,600 km², and the water volume equals 78,648 km³. These parameters indicate that the Caspian Sea contains approximately 44% of the total lake waters of the planet (Mammadov, 2005).

One of the unique features of the Caspian is that it combines both marine and lacustrine characteristics. Salinity levels vary across regions and are primarily regulated by the inflow of large rivers such as the Volga, Ural, Terek, and Kura. This feature makes the Caspian a hydrologically and ecologically unique water body.

Although called a "sea," the Caspian is in fact a closed lake with no natural connection to the world ocean. The absence of such a connection determines distinct dynamics in hydrology, salinity regime, and level fluctuations (Kosarev & Yablonskaya, 1994; Dumont, 1998).

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In terms of hydrological parameters, salinity is about 1–2‰ in the northern part, 10–12‰ in the middle, and 13–14‰ in the southern region (Kosarev, 2005). This factor significantly affects the distribution of fish species in different parts of the Caspian.

In the north, water temperature often drops below freezing in winter (Kosarev & Yablonskaya, 1994), whereas in the south, it varies between +10 and +25°C throughout the year. The main inflows are the Volga, Ural, Kura, and Terek rivers, with the Volga providing about 80% of the total freshwater input. Water level changes are characterized by periodic rises and falls occurring several times per century. At the end of the 20th century, the level rose by about 2.5 meters, while a decreasing trend has been observed in the 21st century. The sharp rise (≈2.5 m) during the late 1970s–1990s and subsequent stabilization are explained by overlapping factors such as increased precipitation in the Volga basin and variations in evaporation rates (Klige, 1997; Panin & Diaconu, 2014).

Aladin and Plotnikov (2004) noted that the hydrological balance is the main determinant of level fluctuations, while short-term effects such as wind-driven surges and seiches can cause local risks in coastal zones.

The Middle and Southern Caspian basins are characterized by a more complex hydrological structure and possess strategic importance for fisheries. In these zones, the common carp (*Cyprinus carpio*) and other representatives of the *Cyprinidae* family play an important ecological and economic role. Their population structure, feeding, and reproductive characteristics are closely related to salinity, the hydrological regime of river deltas, and anthropogenic factors (Hedayati et al., 2017). Therefore, studying the species diversity and biological characteristics of cyprinids in the Middle and Southern Caspian is relevant both scientifically and practically.

Research

Research on *Cyprinidae* fish has examined the ecological features and population dynamics of cyprinids in the Middle and Southern Caspian. However, these studies are mainly based on local observations, and the available data do not provide a comprehensive picture. In the modern era, against the background of climate change, anthropogenic impacts, and fluctuations in water levels, the study of the biological characteristics, adaptation mechanisms, and genetic diversity of cyprinids has become particularly important (Hedayati et al., 2017). Since studies in this field are limited, the scientific investigation of *Cyprinidae* fish in the Middle and Southern Caspian still remains an insufficiently explored area.

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The general systematic position of species belonging to the family *Cyprinidae* is as follows:

Order – *Cypriniformes*

Family – *Cyprinidae* Fleming, 1822

Genus – *Cyprinus* Linnaeus, 1758

Species – *Cyprinus carpio* Linnaeus, 1758

At present, 37 species and subspecies of cyprinids are distributed in the inland water bodies of Azerbaijan. Among them, five species – Shirvan roach, zardaper, Caspian barbel, swordfish, and poru – are included in the *Red Book of Azerbaijan*. In the Kura and Artek basins of the Southern Caspian, the number of species such as the Caspian barbel, shamai, and garasol is low, and therefore their commercial (industrial) importance is insignificant. Since the 1970s, three new cyprinid fish species – grass carp, colorful carp, and silverhead – have been successfully acclimatized in the Caspian Sea (Asgarov & Zaitsev, 1999).

Comparative studies based on various morphometric features have shown that among 20 species and subspecies, clear sexual dimorphism is observed in four (*Pseudorasbora parva*, Lankaran shamai, *Rhodeus sericeus*, and *Carassius gibelio*), weak in fourteen, and absent in two species (Kura barbel and Transcaucasian flatstomach).

During the studies, the number of gill rakers in all gudgeons (368 specimens) collected from different water bodies of Azerbaijan ranged between 36–51. Since this indicator is characteristic only of the silver gudgeon, it has been determined that this is the only species of gudgeon existing in the country's waters. The body color of this fish may vary depending on environmental conditions, ranging from light-silver to dark-golden tones. Some researchers, based on color differences, have described them as a separate species under the name golden gudgeon.

In the mid-20th century, Y.A. Abdurrahmanov described a new species for science – the Soyuqbulaq roach (*Rutilus sojuchbulagi*) – in the spring-fed rivers around the village of Soyuqbulaq, Aghstafa district (*Fauna of Azerbaijan. Vertebrates*, Vol. III, 2004). However, in subsequent studies, including research conducted between 2008 and 2014, this species was not found in that region. It is assumed that due to changes in ecological conditions, its habitat was destroyed, and the species has become extinct in Azerbaijan.

Among other representatives of cyprinids, the *Pseudorasbora parva* and *Hemiculter leucisculus* (Basilewsky, 1855) have been recorded in the water bodies of Azerbaijan. The morphological and biological features of these species have been studied in detail. Their occurrence in the fauna of the country is associated with the process of acclimatization of herbivorous fish. In the external appearance of the *Pseudorasbora parva*, age-related changes are observed: in young individuals, a black stripe is visible along the lateral line, but it disappears with maturity. Its meristic features are similar across different populations, indicating the species' high adaptive capacity. Although biological indicators (length, weight, condition factors, etc.) vary in different regions of the country, the species generally demonstrates adaptation to a wide ecological range. Males are larger and reach sexual maturity at 1–2 years of age.

The *Hemiculter leucisculus* was first recorded in Azerbaijan in the Vilash River, and later became widely distributed in other rivers, reservoirs, and even in the Small Gizilaghaj Bay. Molecular-genetic analyses have confirmed that it belongs to the *Hemiculter leucisculus* species. Morphometric characteristics of the fish show that sexual dimorphism is weakly expressed; however, during the spawning period, certain external changes occur in males. This species is abundantly distributed in freshwater and slightly brackish areas rich in aquatic vegetation. The biological parameters of populations (length, weight, condition factor, fecundity, etc.) vary according to season and age. Females are generally larger than males. The spawning process takes place from May to October, when the water temperature is between 20–23°C.

The *Hemiculter leucisculus* mainly feeds on aquatic plants, but at younger stages it also consumes insect larvae and small crustaceans. Introduced into the Azerbaijani fauna as a result of acclimatization, this fish has now become widespread, affecting native fish species through food

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competition, while simultaneously serving as an important food source for predatory fish (Mustafayev, 2017).

Among the fish species inhabiting the southwestern Caspian, one of the most popular among local populations is the kutum (*Rutilus frisii kutum*), which is found only in the Caspian Sea. Its range extends from the Terek River to the Gorgan Bay. Throughout the year, kutum is mainly observed along the western coasts of the Middle and Southern Caspian, at depths of 9–24 meters. During the summer season, the fish predominantly gathers in the southwestern parts of the sea, particularly around the Gizilaghaj and Anzali bays. On the eastern coast of the Caspian, kutum is less common, but in the Artek–Caspian region, as well as in the Krasnovodsk (now Türkmenbaşy) Gulf and Karshi Bay, it occurs more frequently.

A semi-migratory species, kutum lives mainly in the sea but migrates to rivers for spawning once it reaches sexual maturity — particularly to the Gumbashi, Sefidrud, Lankaran, Kura, Samur, Terek, Sulak, and other rivers (Abdurrahmanov, 1962). Males reach sexual maturity at 3 years of age, while females mature at 4 years. Kutum is a valuable commercial fish species in the Southern and Middle Caspian. In certain years, the annual catch of kutum in the Caspian reached up to 7,000 tons. According to data from 1991–1998, annual kutum catches in Azerbaijan ranged from 3 to 10 tons (Asgarov & Gasimov, 2003).

During 2008–2012, studies conducted in the Lankaran, Boladi, Veravul, Aghstafa, and Soyuqbulaq rivers recorded for the first time in Azerbaijan the presence of the Amur stone moroko – *Pseudorasbora parva* (Temminck et Schlegel, 1846), a representative of the *Cyprinidae* family. A total of 162 specimens of this species were examined using ichthyological methods, and their morphometric and biological parameters were determined. The study also proposed hypotheses regarding the possible routes of introduction of this fish into Azerbaijani waters and its potential impact on local fauna (Mustafayev & Ibrahimov, 2012).

The role of the *Cyprinidae* family in the ecology of the Middle and Southern Caspian Sea is considered multifaceted and significant.

This family represents one of the dominant groups within the ichthyofauna of the Caspian basin and plays an important role in maintaining biodiversity and trophic stability:

1. Formation of biomass – Various cyprinid species such as the common carp (*Cyprinus carpio*), Caspian roach (*Rutilus rutilus caspicus*), Caspian barbel (*Barbus caspius*), and Caspian vimba (*Vimba vimba persa*) are widely distributed in the freshwater and brackish zones of the Caspian Sea. Acting as primary consumers, they feed on benthic and planktonic organisms, forming a large biomass and creating strategic resources for fisheries.
2. Mediator role in the trophic chain – Cyprinids have a wide feeding spectrum, consuming phytoplankton, zooplankton, benthic invertebrates, and detritus, thus functioning as an important link in nutrient cycling. At the same time, they serve as a major food source for predatory fish (e.g., zander – *Sander lucioperca*, sturgeons – *Acipenseridae*) and aquatic birds.
3. Maintaining ecosystem stability – The presence of diverse ecological groups among cyprinids helps to sustain biological balance in aquatic ecosystems. For instance, planktivorous species regulate phytoplankton abundance, while benthophagous species influence the structure of bottom-dwelling communities.
4. Sensitivity to anthropogenic factors and indicator role – In the Middle and Southern Caspian, industrial pollution, hydrotechnical constructions, and fishing pressure have caused notable changes in cyprinid population dynamics. Their abundance and biodiversity indices are widely used as bioindicators of the ecological condition of aquatic ecosystems (Shabani & Fazli, 2018).

Many species of cyprinids (such as the common carp and Caspian roach) constitute the main part of fish stocks in the Caspian Sea and are of strategic importance for both industrial and local fisheries. They are also widely used in aquaculture.

The analysis of existing studies indicates that the Kura basin and the Middle–Southern Caspian region represent one of the main diversity centers of the *Cyprinidae* family. Ichthyological research carried out over the last decade has confirmed the presence of 27 fish species in this basin, most of

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which belong to *Cyprinidae*. Investigations in the Nakhchivan and Kura Delta regions have shown that species such as the common carp (*Cyprinus carpio*) and silver carp (*Carassius gibelio*) are dominant.

Morphometric and bioecological analyses reveal that cyprinid populations exhibit both age and morphological differentiation. Studies conducted in the Southern Caspian confirm that *C. carpio* possesses at least three distinct populations. Feeding and reproductive characteristics indicate that the common carp is a broadly omnivorous species, with its reproductive period mainly occurring during the spring months (Tagiyeva, 2014).

Conclusion

In recent years, the phenomenon of "rejuvenation" observed in Kura River populations indicates that, in addition to intensive fishing pressure, anthropogenic factors also significantly influence the biological structure of the population. This process is accompanied by a decrease in both biomass and the proportion of long-lived individuals.

Existing data on the biological parameters of the common carp in the Caspian basin (length, weight, age, and fecundity) confirm that, although this species possesses a high adaptive potential, it remains sensitive to ecological and anthropogenic pressures. Since the Kura River and its adjacent zones serve as the main reproductive area for the population, their protection and sustainable management are of strategic importance for the persistence of cyprinid species.

Overall, representatives of the *Cyprinidae* family constitute the core of the ichthyofaunal biodiversity and biological stability of the Caspian and Kura basins. The conservation and sustainable use of these species are essential not only on a regional but also on an international scale.

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Study of the Technology of Fattening Fine-Wooled Wool-Meat Male Calves in Breeding Farms in the Ganja-Gazakh Region

Abstract

The article studies the technology of fattening fine-wooled wool-meat male lambs in breeding sheep farms in the Ganja-Gazakh region. The research was conducted at the "Aran" sheep breeding farms in Yevlakh district, "Dostlug" in Beylagan district, Sabir farm in Bilasuvar district, and "Arzu" in Aghdam district. Studying the commercial quality of the wool of the sheep raised here is the most urgent issue in the conditions of a market economy. The results of our research show that in order to meet the population's demand for sheep products, it is necessary to properly organize the feeding, nutrition, and keeping of sheep regardless of the seasons. In particular, sheep should be grazed at night in warm weather in spring, summer, and autumn.

Keywords: *sheep, damazlıq, feed ration, average mass gain, fattening period*

Introduction

Sheep farming also has a special place in eliminating food insecurity in our country. Since sheep are very suitable grazing animals, they are less demanding on feed than cattle. In addition, sheep can effectively use the grass of steppes, mountain slopes, and steep cliffs that are unsuitable for cultivation and that other animals cannot reach (Sadigov, 2022).

Sheep breeding has an ancient history in Azerbaijan. Natural climatic conditions, vast areas of summer and winter pastures have created the basis for the expansion of sheep breeding here. Even in the past, the emergence and development of the art of carpet weaving in our homeland was also associated with sheep breeding. In connection with all this, very serious measures are being taken at the state level to develop sheep breeding in the republic and further increase the number of sheep (Abasov, 2011).

In our country, the recent development (integration) of light industry in a new direction has led to the annual increase in the population's demand for semi-coarse wool raw materials and cheap and fast-growing meat products, which has led to the need to give wide space to the development of fast-growing sheep breeds with semi-coarse wool (Sadigov, 2024).

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Research

Sheep are convenient grazing animals and are relatively undemanding to feed. Sheep make very good use of natural grasses found in desert and semi-desert pastures. Thus, in the pastures of semi-desert regions, cattle consume 66% of plants, while sheep consume only 38%, while cattle can consume only 12% of semi-desert plant species, while sheep consume 30%. Local sheep breeds of Azerbaijan give high weight gain when fattened on pasture and in feedlots (Balakishiyev, 2009).

Sheep farming is one of the profitable sectors of agriculture. The wool, fur, fur coats, and skins used for other purposes in industry, as well as meat and dairy products used by the population, are of particular importance in the national economy. Sheep are very prolific animals and mature quickly. One of the advantages of sheep is their good adaptation to various climatic conditions. For the development of sheep farming, the technique of feeding sheep should be studied in depth and applied to farms by producing sufficient feed (Abdullayev, 2012).

Although the feeding of sheep is similar in principle, it is essentially no different from the feeding of large horned animals. However, since cattle are more active than large horned animals, the nutrients and energy consumed per 1 kg of live weight are much higher. A total of 3.2–3.8 kg of dry matter is required for every 100 kg of live weight, and when granulated dry feeding is used, the demand for dry matter increases to 4.2–4.5 kg. By applying different types of feeding in the feeding of cattle, feed rations with different compositions are applied, depending on the breed, productivity direction, and use (Taghiyev, 2023).

In most farms in our republic, mutton production is mainly carried out by feeding old sheep on natural pastures and then slaughtering them for meat. However, the experience of leading farms shows that fattening sheep on a fattening farm is more efficient than feeding them on pasture (Tahirova, 2018).

Materials and Methods. In our experiments, in order to study the technology of sheep fattening, 50 male 15–16-month-old rams that were not suitable for breeding were selected from the state farms "Aran" of Yevlakh district, "Dostlug" of Beylagan district, Sabir of Bilasuvar district and Aghdam district, and fattening herds were organized in each farm, and they were fattened on summer pastures for 3 months (July, August, September). As we know, sheep in Azerbaijan are mainly grazed on pastures in spring, summer, autumn, and winter. We organized the feeding, nutrition, and keeping of the rams in such a way that the rams were always in good condition. However, during the wintering period, we fed the rams with daily strong, coarse, and juicy feeds according to their needs.

The results of feeding male calves on summer pastures are given in Table 1 below.

Table 1. Fattening male calves on pasture.

Farm name	Number of heads	Fattening period, days	Average mass, kg		Average mass gain	
			Of fattening		during the fattening period, kg	per day, g
			before	end		
Aran	50	90	43,2	49,7	6,5	72,3
Friendship	50	90	41,4	47,7	6,3	69,2
Sabir	50	90	39,6	45,4	5,8	64,5
Arzu	50	90	40,8	46,8	6,0	66,3

It is clear from Table 1 that as a result of fattening male bulls unsuitable for breeding on summer pastures for 90 days, the average mass gain at the "Aran" farm was 6.5 kg, daily gain was 72.3 g, and the average mass at the end of fattening was 49.7 kg, respectively, at the "Dostlug" farm it was 6.3 kg, 69. g and 47.7 kg, at the "Sabir" farm it was 5.8 kg, 64.5 g and 45.4 kg, and at the "Arzu" farm it was 6 kg, 66.3 g and 46.8 kg.

After fattening on summer pastures, the male bulls intended for meat were fattened on the fattening for 60 days in the fattening sheds.

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The experimental animals were fed with the following feed rations at the "Aran" and "Dostlug" farms.

Table 2. Feed ration of sheep fattened in the Aran and Dostluq farms.

Feeds	**Quantity**
Clover grass, kg	0,7
Corn silage, kg	2,0
Barley groats, kg	0,4
Feed unit	1,1
Digestible protein, g	124

Sheep fattened in the Sabir and Arzu farms were fed with the following feed rations.

Table 3. Feed rations of sheep fattened in the Sabir farm.

Feeds	**Quantity**
Corn silage, kg	5,0
Barley groats, kg	0,4
Feed unit	1,2
Digestible protein, g	108

It should be noted that both feed rations comply with zootechnical standards in terms of nutritional value. Free-range feeding was organized for the fattening sheep, and a sufficient amount of table salt was placed in their feed troughs in the form of licks. The results of fattening male lambs in the barn are given in the table below.

Table 4. Fattening of male calves in the barn.

Farm name	**Number of heads**	**Fattening period, days**	**Average mass, kg**		**Average mass gain**	
			Of fattening		**during the fattening period, kg**	**per day, g**
			before	**end**		
Aran	50	60	49,7	56,3	6,6	110
Friendship	50	60	47,7	54,5	5,8	97
Sabir	50	60	45,4	50,5	5,1	85
Arzu	50	60	46,8	51,6	4,8	80

The data in Table 4 shows that as a result of fattening male lambs unsuitable for breeding on a fattening rack for 60 days after pasture fattening, the average mass gain at the Aran farm was 6.6 kg, daily gain was 110 g, and the average mass at the end of fattening was 56.3 kg; respectively, at the Dostluq farm it was 5.8 kg, 97 g and 54.5 kg, at the Sabir farm it was 5.1 kg, 85 g and 50.5 kg, and at the Arzu farm it was 4.8 kg, 80 g and 51.6 kg. These indicators prove that the efficiency of autumn fattening of sheep on a fattening rack is mainly based on the correct use of feed. In normal pastures with fertile ecological conditions, up to 75% of the nutrients of the feed eaten by lambs are spent on crop production. This directly affects the low cost of the product. People use various types of grasses, including weeds, throughout the year.

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Conclusion

Based on our scientific research, we can say that, along with the external environment, the feeding, sex, and age of sheep directly affect their productivity. It is known that as age increases, the density of fibers in the flocks also begins to increase. Research work in breeding farms was carried out in accordance with the methodology, work program, and calendar plan developed and approved for 2021–2025.

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Application Prospects of Hydrazone-Based Organic Ligands

Abstract

Hydrazone-based organic ligands represent a versatile class of compounds that have gained considerable attention in coordination chemistry and medicinal research due to their unique structural features and diverse functional properties. These ligands, characterized by the presence of an azomethine (–C=NNH–) group, can act as nitrogen–nitrogen donor systems, facilitating the formation of stable complexes with a wide range of metal ions. Recent studies have highlighted their potential in catalysis, metal sensing, and drug design, including antimicrobial, antifungal, and anticancer applications. The tunability of substituents on the hydrazone backbone allows for modulation of both electronic and steric properties, thereby influencing the stability, selectivity, and biological activity of the resulting complexes. This review systematically examines the recent advances in the synthesis, coordination behavior, and application prospects of hydrazone-based ligands. Key trends in ligand design, structure–activity relationships, and emerging therapeutic and industrial applications are discussed. This research provides a systematic review of the existing literature, revealing the promising possibilities of hydrazone ligands as functional molecules in organic synthesis and biomedicine.

Keywords: *hydrazone, ligand, complexes, organic synthesis, catalysis, biological activity, medicine*

Introduction

Hydrazones are a class of organic compounds formed by the condensation of carbonyl compounds with hydrazine and have the general formula $R_1R_2C=NNH_2$. These compounds contain a nitrogen–nitrogen (–N=NH–) bond, which gives their chemical properties a unique dynamism and reactivity. Hydrazones can be stable both free and in the form of complexes with metal ions. Their structural flexibility and functional diversity make hydrazones suitable for a wide range of applications in chemistry, materials science, and biotechnology (Abd El-Wahab, 2015).

The structure of hydrazones can be modified by both electronic and steric factors. These modifications change their coordination behavior, protonation ability, and electron donor/acceptor properties. These properties make hydrazones attractive for the synthesis of organometallic complexes and for the preparation of various catalytic and functional materials. In recent years, hydrazones have gained relevance as objects of research in organic and coordination chemistry. Their ability to complex with various metal ions, as well as their tautomeric and conjugation properties, are of interest in terms of chemical reactivity and stability. Hydrazones are also applied as key components in molecular engineering, material design, and sensor technologies.

Structurally, hydrazones can be synthesized as aromatic and aliphatic derivatives. Hydrazones combined with aromatic systems form more stable and colorful complexes, while aliphatic hydrazones are more reactive and allow for various chemical transformations. This structural flexibility allows researchers to design hydrazones for specific purposes. Hydrazones can also act as proton and electron acceptors and donors, which makes them important actors in redox and coordination chemistry. These properties make hydrazones have a wide range of applications in catalysis, sensors, polymer and material science. Thus, hydrazone-based organic ligands are relevant as a multidisciplinary research object in various fields of chemistry.

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Their chemical structure, coordination ability, and functional flexibility make them even more important for both fundamental and applied research.

Materials and Methods

This study mainly used the method of theoretical generalization of scientific literature. The synthesis methods, chemical properties, and practical applications of hydrazone derivatives presented in various studies were systematized and analyzed.

From a methodological point of view, the article covers three directions:

- Structural analysis: Functional groups of hydrazones and their complexation mechanisms with metal ions were reviewed.
- Application directions: Information on their use in biological, catalytic, and material sciences was grouped.
- Perspective approaches: Analytical results on the future applications of hydrazones in green chemistry and nanotechnology were presented.

Research

Biological and pharmacological importance. Hydrazone derivatives are one of the most studied organic classes in terms of biological activity. Since their structure can be modified both electronically and sterically, they can be directed against various biological targets (Shikhaliyev, 2025). This property makes hydrazones suitable for use as antimicrobial, antiviral, antifungal, and antitumor agents (Mathew, 2015). Analyses of the intracellular mechanisms of hydrazone–metal complexes have shown that these compounds reduce cellular stress and activate apoptotic mechanisms by regulating the generation of reactive oxygen species (Charan, 2025). In particular, Cu(II), Ni(II), Zn(II), and Fe(III) complexes have demonstrated high anticancer activity. In addition, hydrazones can also act as enzyme inhibitors, which is considered an important direction in the design of new pharmacological drugs (Guimaraes, 2017).

Importance in catalytic and synthetic chemistry. Hydrazone ligands play an important role in both homogeneous and heterogeneous processes in catalytic systems. They stabilize the coordination of transition metals, increase the selectivity of reactions, and enable the formation of energy-efficient mechanisms. For example, hydrazone-based catalysts provide high yields and selectivity in three-component reactions of type A^3 (consisting of aldehyde, amine, and alkyne) (Mali, 2021). In addition, these ligands are also effective in carbon–hydrogen functionalization, oxidation, and reduction reactions. Another area of particular importance in terms of catalysis is the chemical fixation of carbon dioxide (CO_2) (Xu, 2018). The electron donor–acceptor properties of hydrazone derivatives facilitate the activation of CO_2 molecules and their conversion into various organic compounds. This is important in terms of the development of environmentally safe, sustainable processes in the direction of green chemistry (Sun, 2025).

Application in materials science and nanotechnology. The application of hydrazones in materials science has increased dramatically in recent years. Polymers with hydrazone functional groups, when complexed with metals, form materials with high mechanical strength and thermal stability (Tai, 2018). Hydrazone bonds are also used as the main connecting element in the construction of covalent organic frameworks (COFs). Such COFs have important potential in gas adsorption, energy storage, and ion exchange systems. The role of hydrazones in the synthesis of nanomaterials is even broader. Their reducing and directing properties allow controlling the morphology of metal and semiconductor nanoparticles. For example, in the formation of materials such as ZnSe and CdS, hydrazones help control particle size and surface morphology. These properties open up new possibilities for important applications in the fields of optoelectronics and photocatalysis (Florence, 2015).

Analytical and environmental chemistry directions. Hydrazone derivatives are widely used as analytical reagents with high selectivity and sensitivity. Their main application is the determination and monitoring of metal ion concentrations (Hanif, 2019). Hydrazone sensors, which act as fluorescent and color indicators, are effective in detecting ions such as Zn^{2+}, Cu^{2+}, Fe^{3+}, and Hg^{2+}. The advantage of hydrazone-based sensors is that they remain stable in the aquatic environment and

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provide results in a short time. This makes it possible to use them in ecological analysis systems to determine the level of environmental pollution (Jabeen, 2022).

Industry and polymer technology. Hydrazone compounds are widely used in industry as polymer stabilizers, adhesives, textile modifiers, and corrosion inhibitors. Their chemical stability and heat resistance make hydrazones suitable for the preparation of long-lasting materials. In addition, some hydrazone derivatives have photoreactive and color-changing properties, which make them promising components in the design of optical sensors and smart materials (Zhuang, 2024).

Conclusion

The conducted analyses show that hydrazone-based compounds have a wide range of application potential. Structural flexibility and chemical stability make this class promising for the creation of functional materials in various fields — especially in catalysis, medicinal chemistry, materials science, and analytical chemistry. The ability of hydrazones to form complexes with metal ions makes them important both as the main component of catalytic systems and as a component of biologically active substances. In terms of biological activity, the enzyme-inhibitory, antimicrobial, and antitumor properties of hydrazone derivatives make them suitable for use in drug design. Increasing selectivity and reducing toxicity through structural modifications further strengthens the importance of these compounds in clinical and molecular biology research.

The application of hydrazone ligands in catalytic processes increases the selectivity and efficiency of reactions and ensures the stability of metal complexes. In particular, in reactions such as C–H functionalization, oxidation–reduction, and chemical fixation of carbon dioxide, hydrazones allow the construction of sustainable catalytic systems in accordance with the principles of green chemistry.

In the field of materials science, the use of hydrazone-based covalent organic frameworks and polymers in the fields of energy storage, gas adsorption, ion exchange, and nanomaterial synthesis promises important results. Controlling the morphological properties of these materials opens up a wide range of applications in photocatalysis, optoelectronics, and sensor technology.

In analytical chemistry, the use of hydrazone derivatives as reagents with high selectivity and sensitivity increases their importance in the detection of metal ions and environmental monitoring.

Overall, future research on hydrazone-based compounds should focus on a deeper understanding of their structure–function relationships and the design of new functional materials and environmentally sustainable systems. Research in the fields of molecular engineering, nanomaterial synthesis, and biological applications will further strengthen the strategic role of hydrazones in science and industry.

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