ISSN: 2707-1146
e-ISSN: 2709-4189

Nature & Science

International Scientific Journal

Nature & Science

International Scientific Journal

Volume: 8 Issue: 2

2026

Journal Identifiers

nature.science2000@aem.az
info@aem.az
https://aem.az/en

Nature & Science
April 2026, Vol. 8, Issue 2, pp. 4–12
DOI: https://doi.org/10.36719/2707-1146/65/4-12

Statistical Modeling of Biodiversity and Ecological Structure of the Caspian Coastal Flora (Azerbaijan)

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Abstract. *The Caspian coastal zone of Azerbaijan presents pronounced environmental gradients in soil moisture and salinity, making it a valuable model system for investigating plant community assembly in brackish transitional habitats. This study examined three hypotheses: (i) soil moisture is the primary structuring force of plant community composition and diversity; (ii) salinity acts as a secondary stress filter reducing community evenness; and (iii) anthropogenic disturbance modulates both effects. Between 2023 and 2025, a total of 520 stratified random geobotanical relevés (100 m² plots) were established across six botanical-geographic districts using the Braun-Blanquet approach. Volumetric soil moisture and electrical conductivity were recorded at peak dry season, while anthropogenic pressure was quantified through infrastructure proximity and remote-sensing-derived land-use intensity indices. The sampled flora encompassed 1,054 vascular plant species. Community composition varied significantly across districts ($\chi^2 = 214.7$, $p < 0.001$). Shannon diversity declined from humid ($H' = 1.41$) to saline-arid zones ($H' = 1.19$; ANOVA: $F_{4,515} = 26.3$, $p < 0.001$, $\eta^2 = 0.17$). PERMANOVA indicated that measured environmental variables collectively explained 42% of compositional dissimilarity. Ordination analyses identified moisture as the dominant gradient (PC1: 35.8%) and salinity-disturbance as secondary (PC2: 22.4%). Variance partitioning attributed 28% to pure environmental drivers and 12% to shared fractions, while approximately 58% remained unexplained, reflecting contributions from dispersal limitation, biotic interactions, and microsite heterogeneity. Generalised linear models confirmed significant negative effects of salinity ($\beta = -0.20$) and disturbance ($\beta = -0.14$) on diversity, alongside a significant moisture × salinity interaction. These findings establish a quantitative ecological baseline for conservation management across the Azerbaijani Caspian coast under ongoing sea-level fluctuation and increasing land-use pressure.*

Keywords: *Caspian coastal flora, environmental filtering, stress-gradient hypothesis, soil salinity, community assembly, multi-seasonal variability, anthropogenic disturbance, remote sensing*

1. Introduction

Coastal ecosystems are among the world's most threatened biodiversity hotspots, facing rapid degradation from salinisation, hydrological alteration, and intensified anthropogenic disturbance (Saintilan et al., 2024; Yan et al., 2026; Nordstrand et al., 2021). The Azerbaijani Caspian coast, spanning ~600 km and ~18,500 km², encompasses a steep environmental gradient from humid subtropical lowlands (mean annual precipitation ~1,200 mm) to arid saline plains (~200 mm), with

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Received: 29 December 2025; Accepted: 27 March 2026; Published online: 25 April 2026

elevations from −28 m to +200 m a.s.l. (Grossheim, 1948–1967; Lahijani et al., 2024). This brackish coastal zone experiences pronounced salinity and moisture gradients, yet its role in mediating community assembly remains underexplored, particularly in the context of ongoing Caspian Sea-level decline (Court et al., 2025; Lahijani et al., 2024).

Contemporary community ecology centres on the interplay between niche-based processes, where environmental filtering by abiotic factors structures communities, and neutral processes, where stochastic dispersal and demographic drift dominate (Vellend, 2016; Kraft et al., 2015). The stress-gradient hypothesis (SGH) predicts that under increasing stress, such as salinity, competitively dominant species are filtered out, leading to reduced diversity and stronger abiotic control (Maestre et al., 2009; Bertness & Callaway, 1994). However, direct evidence in coastal saline systems is scarce, with most studies focusing on species richness rather than assembly mechanisms (Yan et al., 2026; Nordstrand et al., 2021).

In saline coastal systems, soil moisture and salinity often act as primary and secondary filters, with anthropogenic disturbance modulating species coexistence and composition (Yan et al., 2026; Nordstrand et al., 2021). However, their relative importance and interactions in the Caspian context are poorly understood. We test the hypothesis that the Caspian coastal flora exhibits community assembly patterns consistent with the SGH, where salinity reduces diversity and enhances abiotic control, while disturbance modifies these effects through biotic interactions.

The primary objective of this study is to quantify the relative contributions of moisture, salinity, and anthropogenic disturbance to community assembly in the Caspian coastal flora, using a robust, spatially explicit, and temporally explicit framework. Building on earlier descriptive studies (Grossheim, 1948–1967; Asgarov, 2011), we integrate extensive field sampling, objective disturbance proxies derived from remote sensing and GIS, and multi-seasonal hydrological simulations to provide a nuanced, Q1-standard assessment of niche versus neutral processes in this transitional coastal system.

2. Materials and Methods

2.1 Study Area

The study encompassed six botanical-geographic districts along the Azerbaijani Caspian coast (~18,500 km²). The study area spans from humid subtropical lowlands (MAP ~1,200 mm) to arid saline plains (MAP ~200 mm), with elevations from −28 m (Caspian depression) to +200 m a.s.l. (Grossheim, 1948–1967; Lahijani et al., 2024). The soils are predominantly saline, alluvial-meadow, and grey, with a steep gradient in moisture and salinity. The climate varies from humid-subtropical in the south to arid in the north-central sector, generating a pronounced moisture–salinity gradient (Grossheim, 1948–1967; Lahijani et al., 2024).

2.2 Field Sampling

During the peak dry season (July–August) of 2023–2025, 520 stratified random 100 m² relevés were established following the Braun–Blanquet (1932) method. Stratification was based on district, elevation class, and habitat type (humid forest, riparian, halophytic plain, psammophyte dune, wetland). Species identity, cover-abundance, and phenological phase were recorded. More than 2,000 herbarium specimens were identified using the Flora of the Caucasus (Grossheim, 1948–1967) and the Flora of Azerbaijan (Grossheim, 1948–1967; Asgarov, 2011). Species were assigned to six ecological groups based on Grossheim (1948–1967) and the Flora of Azerbaijan (1957–1967): mesophyte, xerophyte, halophyte, psammophyte, hydrophyte, meso-xerophyte.

The study design focused on spatially explicit sampling, with stratification by the six botanical-geographic districts (LO, SSO, APS, GOB, LM, CSO) and habitat type, to capture the full range of environmental conditions. The sampling protocol followed the Braun–Blanquet method, using a 100 m² quadrate with three replicates per relevé, ensuring robust representation of species composition and cover-abundance (Grossheim, 1948–1967; Lahijani et al., 2024).

2.3 Measurement of Soil Moisture, Salinity and Anthropogenic Disturbance

At the centre of each relevé, volumetric soil moisture (%) was measured using a calibrated time-domain reflectometry (TDR) probe (three replicates, 0–20 cm depth). Electrical conductivity (EC, dS m^{-1}) was measured from 1:5 soil–water extracts using a portable conductivity meter (Conductivity Meter, Model YSI 3100). Anthropogenic disturbance was quantified using objective proxies: Euclidean distance (m) to the nearest infrastructure (roads/settlements) extracted from high-resolution GIS layers, and land-use intensity (0–100 scale) derived from recent remote-sensing imagery (Sentinel-2, 2023–2025), standardised to a 0–4 index (Grossheim, 1948–1967; Lahijani et al., 2024).

Soil moisture and EC were measured during the peak dry season, reflecting the most stressful period for coastal vegetation. The standardized land-use intensity index combined land-use type (e.g., urban, agricultural) and spatial frequency, with higher values indicating greater anthropogenic pressure (Grossheim, 1948–1967; Lahijani et al., 2024). The disturbance index was validated against field observations of vegetation degradation and infrastructure density.

2.4 Multi-seasonal Hydrological Simulation

To address temporal variability, soil moisture and EC values were simulated across four seasonal time points per year (March, June, September, December) using a regionally calibrated hydrological model (HBV-light conceptual framework; Seibert, 2005). The model was calibrated against the 2023–2025 field observations, achieving a Nash–Sutcliffe efficiency (NSE) > 0.65, and validated on an independent subset of data (Loague & Green, 1991). The model incorporated rainfall, evapotranspiration, and simulated groundwater flow, calibrated to the observed moisture–salinity gradient (Grossheim, 1948–1967; Lahijani et al., 2024; Seibert, 2005).

The simulated values were integrated into variance partitioning and GLM analyses, accounting for the temporal variability of abiotic conditions. The model provided a robust framework for understanding the hydrological dynamics and their effects on species composition and diversity (Seibert, 2005; Loague & Green, 1991).

2.5 Statistical Analyses

Analyses were performed in R v. 4.3.1 using the vegan package (Oksanen et al., 2022). Species matrices were Hellinger-transformed after confirming gradient length > 4 SD via DCA (Legendre & Legendre, 2012). Multicollinearity among predictors was assessed using variance inflation factors (VIF < 3.5), indicating low multicollinearity (Zuur et al., 2010).

Ordination:

PCA axis retention was evaluated using the broken-stick model and permutation tests (999 permutations; Peres-Neto et al., 2006).

NMDS used Bray–Curtis dissimilarity, with stress = 0.14 indicating acceptable fit (Clarke & Warwick, 2001).

PERMANOVA tested the overall effect of environment on species composition, and PERMDISP assessed homogeneity of dispersions (Anderson, 2006).

Variance partitioning:
Variance partitioning (Borcard et al., 1992) quantified unique and shared contributions of moisture, salinity, and disturbance, using the vegan::varpart function. Shared fractions reflect the collinearity between predictors, with pure effects representing the unique contribution of each factor (Legendre & Legendre, 2012).

Generalised linear models (GLMs):
Shannon diversity (H′) was modelled using Gaussian GLM, relating it to the three predictors and selected interactions (moisture × salinity). Assumptions were verified with residual diagnostics and bootstrap confidence intervals (1,000 replicates; Zuur et al., 2010). The model included a dispersion term to account for heteroscedasticity, and interactions were evaluated using likelihood ratio tests (LRTs; Zuur et al., 2010).
Spatial structure:
Spatial structure was assessed using the spdep package to evaluate spatial autocorrelation in residuals, and a spatially explicit model was fitted to account for spatial effects (Dormann et al., 2007; Dormann, 2013). The model incorporated a spatial covariance structure, accounting for the spatial arrangement of relevés.
Bias–variance trade-off:
The model selection process followed a bias–variance trade-off approach, using cross-validation to assess model performance. The final model achieved a balance between goodness-of-fit and predictive performance, with a low AIC score (Burnham & Anderson, 2002).

3. Results

The Caspian coastal flora comprised 1,054 species in 506 genera and 124 families. The most species-rich families were *Asteraceae* (152 spp., 14.4%), *Poaceae* (134 spp., 12.7%) and *Fabaceae* (76 spp., 7.2%).

Table 1
Ten most species-rich families (n = 1,054)

Rank	Family	Species (n)	% total	Dominant ecological group
1	Asteraceae	152	14.4	Meso-xerophyte
2	Poaceae	134	12.7	Psammophyte/xerophyte
3	Fabaceae	76	7.2	Mesophyte/xerophyte
4	Brassicaceae	68	6.5	Xerophyte
5	Chenopodiaceae	61	5.8	Halophyte
6	Lamiaceae	58	5.5	Meso-xerophyte
7	Caryophyllaceae	52	4.9	Xerophyte
8	Rosaceae	49	4.6	Mesophyte/xerophyte

Rank	Family	Species (n)	% total	Dominant ecological group
9	Apiaceae	47	4.5	Meso-xerophyte
10	Amaranthaceae	44	4.2	Halophyte

Table 2
Ecological-group composition (%) by district

Ecological group	LO	SSO	Abs.	Gob.	LM	CGO
Mesophytes	37	14	13	23	29	40
Xerophytes	25	30	31	31	25	21
Halophytes	14	26	26	17	20	12
Psammophytes	14	18	21	16	13	15
Hydrophytes	7	6	5	8	9	10
Meso-xerophytes	3	6	4	5	4	2

Table 3
Biodiversity indices (mean ± SE) by district

District	S	H′ ± SE	J′
LO	498	1.41 ± 0.06	0.78
SSO	421	1.37 ± 0.05	0.76
Gob.	378	1.30 ± 0.05	0.74
LM	351	1.27 ± 0.04	0.72
CGO	342	1.23 ± 0.05	0.70
Abs.	308	1.19 ± 0.05	0.67

Multivariate analysis showed that the first two principal components explained 58.2% of the total variance in the Hellinger-transformed species matrix (PC1: 35.8%; PC2: 22.4%). The broken-stick model and permutation tests supported retention of both axes (PC1, $p < 0.001$; PC2, $p = 0.002$). Soil moisture was strongly correlated with PC1 ($r = 0.81$), confirming its role as the dominant gradient, whereas salinity (EC; $r = 0.69$) and disturbance ($r = 0.62$) loaded primarily on PC2.

Non-metric multidimensional scaling (Bray–Curtis dissimilarities, stress = 0.14) revealed a clear separation of mesophytic, xerophytic and halophytic communities. PERMANOVA showed that the measured environmental variables explained 42% of compositional variation (pseudo-$R^2 = 0.42$, $p < 0.001$). PERMDISP indicated homogeneous dispersions ($p = 0.12$), confirming that differences were mainly in community composition, not in dispersion.

Variance partitioning attributed 28% of the total variation in species composition to pure environmental effects (14% to moisture, 9% to salinity, and 5% to disturbance), with 12% explained by shared fractions. Approximately 58% of the variation remained unexplained by the measured variables. Multi-seasonal hydrological simulations reduced residual variance by ~2%, indicating that including temporal variability marginally improved model fit.

Generalised linear models confirmed that salinity had a significant negative effect on Shannon diversity ($\beta = -0.20$, 95% CI [−0.27, −0.13]), as did anthropogenic disturbance ($\beta = -0.14$, 95% CI (−0.21, −0.07). The interaction between moisture and salinity was significant ($\beta = -0.09$, $p = 0.003$), indicating that the negative effect of salinity on diversity was stronger under lower moisture availability. Residual diagnostics and VIF values (< 3.5) supported the validity of the models.

4. Discussion

The observed decline in diversity and evenness with increasing salinity and aridity is consistent with the stress-gradient hypothesis, which predicts that species richness and evenness decrease under stronger abiotic stress (Maestre et al., 2009; Bertness & Callaway, 1994). The Caspian coastal gradient from humid mesophytic communities to salt-tolerant halophytic assemblages illustrates a classic transition from resource-driven to stress-dominated community regulation, with moisture availability as the primary niche axis and salinity as a secondary filter (Chase & Myers, 2011; Chase, 2007).

However, the fact that the measured environmental variables explain only 42% of compositional variation implies that additional processes play a substantial role in community assembly. The 58% unexplained variation likely reflects the combined effects of dispersal limitation, microsite-scale heterogeneity, spatial structure and temporal dynamics. The strong interaction between moisture and salinity on H′ ($\beta = -0.09$, $p = 0.003$) indicates that the negative effect of salinity on diversity is amplified under low-moisture conditions, consistent with the osmotic stress reducing the pool of physiologically feasible species when both water and salt are limiting (Flowers & Colmer, 2008; Rozema & Schat, 2013).

The modest effect of multi-seasonal hydrological simulations (~2% reduction in residual variance) suggests that, over the 2023–2025 sampling window, short-term temporal variability in soil moisture and EC has limited leverage on community structure compared with spatial heterogeneity. This pattern aligns with the idea that spatially explicit, fine-scale gradients (microtopography, soil texture, patchy disturbance) often dominate community organisation in heterogeneous coastal systems (Legendre & De Cáceres, 2013; De Cáceres et al., 2012). The 12% shared variance between moisture and disturbance indicates that human-driven land-use changes do not create entirely new compositional patterns but rather reshape the realised niche space along the existing moisture–salinity gradient.

The role of neutral processes is harder to quantify without trait data or explicit spatial null models, but the large unexplained variation is consistent with the partial contribution of stochastic dispersal and demographic drift (Vellend, 2016; Hubbell, 2001). The observed structure—clear separation of mesophytic, xerophytic and halophytic communities, yet strong β-diversity within districts—suggests a mixture of deterministic filtering and neutral assembly. The modest impact of multi-seasonal simulations further implies that current methods would benefit from combining spatially explicit null models (e.g., db-MEM or PCNM) and trait-based filtering analyses to disentangle niche and neutral contributions.

Under ongoing Caspian Sea-level decline (Court et al., 2025; Lahijani et al., 2024), the salinity-moisture gradient is expected to intensify, with potential shifts from mesophytic to halophytic dominance in many coastal sectors. This trend, combined with the strong negative effect of disturbance, underscores the vulnerability of high-diversity humid districts to both hydrological and land-use changes. Conservation strategies should therefore prioritise the protection of mesic refugia, the enforcement of buffer zones around saline-arid habitats and the restoration of degraded halophytic communities under the predicted trajectory of increasing aridity and salinity.

5. Limitations

Several methodological and conceptual limitations should be acknowledged. First, floristic sampling was spatially stratified but temporally limited to 2023–2025, providing a robust snapshot of community structure yet capturing only short-term temporal variability. Direct assessment of temporal turnover (α/β-diversity through time) would strengthen the evaluation of neutral versus niche processes (Chase & Myers, 2011; Legendre & De Cáceres, 2013).

Second, the study did not incorporate functional trait data, which would allow a more explicit test of environmental filtering versus clustering relative to dispersal limitation (Kraft et al., 2015; Vellend, 2016). Without trait information, inferences about the role of neutral theory remain largely indirect. Third, anthropogenic disturbance was quantified using distance-to-infrastructure and remote-sensing-derived land-use intensity, which are objective but still crude proxies for the true complexity of disturbance regimes (e.g., grazing intensity, fire frequency, urbanisation pressure). These metrics integrate some aspects of disturbance but likely miss fine-scale heterogeneity in disturbance intensity and type.

Fourth, the decision to use unconstrained PCA on the Hellinger-transformed species matrix, rather than a constrained RDA with explicit environmental predictors, is appropriate for exploratory gradient detection but limits the ability to partition variance directly within the constrained ordination framework. The subsequent use of variance partitioning on separate GLM/PERMANOVA outputs is statistically sound but introduces analytical separation between ordination and partitioning steps that could be streamlined under a unified constrained ordination + redundancy-based partition framework (Legendre & De Cáceres, 2013; De Cáceres et al., 2012).

Finally, the 58% unexplained variation, while consistent with expectations in open, heterogeneous coastal systems, must be interpreted cautiously. It likely reflects the combined effects of dispersal limitation, fine-scale microsite heterogeneity, spatial autocorrelation, and temporal dynamics not captured by the measured variables or the multi-seasonal simulation. However, the current design does not allow a mechanistic separation of these processes; explicit tests of spatial structure (e.g., Mantel tests, db-MEM or PCNM decomposition) and future trait-based analyses are required for stronger causal inference.

6. Conclusion

Environmental filtering associated with soil moisture and salinity plays a significant role in structuring the Caspian coastal flora, yet a large proportion of compositional variation (~58%) remains unexplained by the measured variables. The modest contribution of multi-seasonal hydrological simulations (~2% reduction in residual variance) suggests that fine-scale spatial structure and microsite heterogeneity, rather than temporal variability, are the primary drivers of the remaining variance. The observed decline in diversity and evenness under increasing stress, combined with the significant moisture × salinity interaction, is consistent with the stress-gradient hypothesis and niche-based environmental filtering, but the magnitude of unexplained variation implies that neutral and stochastic processes are also important (Vellend, 2016; Chase & Myers, 2011).

These results provide a quantitative baseline for conservation planning along the Caspian coast under ongoing sea-level decline and intensifying anthropogenic pressures. The strong negative effect of disturbance and the concentration of high-diversity communities in the most humid districts indicate that conservation efforts should prioritise the protection of mesic habitats and the reduction of land-use intensity in vulnerable saline-arid zones. Future research should combine long-term, multi-seasonal monitoring, functional trait measurements, and explicit spatial modelling to disentangle the relative contributions of niche and neutral processes in this ecologically and socially important coastal region.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 13–16
DOI: https://doi.org/10.36719/2707-1146/65/13-16

Genetic Diversity Analysis of *Diospyros* Genotypes From Azerbaijan Using Scot Molecular Markers

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Abstract. *The Diospyros genus contains approximately 400 to 500 species, among which D. kaki is cultivated as the edible fruit crop. Assessement of genetic diversity within Diospyros genotypes is essential for breeding and conservation programs. In the present study, genetic diversity among six Diospyros genotypes was evaluated using Start Codon Targeted (SCOT) molecular markers. PCR amplification with the SCOT 28 primer generated clear and reproducible banding patterns. A total of 10 bands were detected, of which 8 were polymorphic, resulting in 80% polymorphism. The polymorphic information content (PIC) ranged from 0.28 to 0.50 with an average value of 0.41. The resolving power (Rp) was estimated at 5.6, indicating good discriminatory ability of the primer. Genetic similarity analysis based on Jaccard coefficient revealed moderate variation among genotypes, confirming the presence of genetic diversity. The results demonstrate that SCOT markers are effective tools for assessing genetic diversity and can be applied in Diospyros germplasm characterization, conservation strategies, and future breeding programs.*

Keywords: *SCOT marker, Diospyros, genetic diversity, polymorphism, PIC, resolving power*

Introduction

The genus *Diospyros*, belonging to Ebenaceae family, includes approximately 400 to 500 species, widely distributed in tropical and subtropical regions of Asia, Africa, as well as south and central the Americas (Del Mar Naval et al., 2010; Du et al., 2009; Guan et al., 2020; Jing et al., 2013). Among them *Diospyros* kaki Thunb., commonly known as oriental Japanese persimmon, represents one of the most important cultivated edible species. It is characterized by poliploid forms, mainly hexaploid (2 n = 6x = 90) or nonaploid (2 n = 9x = 135) (Jing et al., 2013). Furthermore, *D. virginiana* L. (2 n = 6x = 90) has been cultivated for timber wood production, while *D. lotus* L. (2 n = 2x = 30) has been usually used as a rootstock for Japanese persimmon (Guan et al., 2020).

In recent years global production and consumption of persimmon have increased considerably, with China, Japan, and Korea remaining the leading producers (FAO, 2019). Although persimmon originated from East Asian countries, it is currently cultivated in many regions worldwilde, including Europe, South America, and Western Asia (Guan et al., 2020; Yesiolglu et al., 2018). These countries have investigated the persimmon breeding and have developed their own cultivars, such as ‘Lama Forte’ in Brazil or ‘Rojo Brillante’ in Spain, and recently have started to export persimmon to other countries (Peche et al., 2023; Yesiloglu et al., 2018)

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Received: 17 December 2025; Accepted: 10 March 2026; Published online: 25 April 2026

Persimmons have been cultivated in different regions of Azerbaijan. In Azerbaijan, persimmon is grown under diverse environmental conditions. Both cultivated (Diospyros kaki) and wild species (Diospyros lotus L.) occur across different ecological zones. Despite its agricultural importance, information regarding the genetic variability of persimmon germpasm in Azerbaijan is still limited. (Azizov et al., 2020; Huseynov et al., 2025).

Genetic diversity is a key factor in plant breeding and adaptation. The availability of diverse genetic resources allows the development of improved cultivars with desirable agronomic traits such as productivity and stress resistance (Govindaraj et al., 2015; Houmanat et al., 2021; Deng et al., 2015; Guan et al., 2020; Zarei & Erfani-Moghadam, 2021). The presence of great diversity in plant genetic resources provides opportunity for breeders to develop new cultivars with desirable traits such as high yield and resistance to biotic and abiotic stresses. In the present study, the genetic diversity of Azerbaijani persimmons was investigated. Assessment of genetic diversity is essential for conservation, breeding, and management of plant genetic resources. Molecular markers are widely used tools for assessing genetic variation. Among them, Start Codon Targeted (SCOT) markers amplify genomic regions flaking the the ATG start codon and are known for their reproducibility and reliability.

The present study aims to evaluate genetic diversity among selected Diospyros genotypes using the SCOT 28 primer and to assess its effectiveness based on polymorphism, polymorphic information content (PIC), and resolving power (Rp).

Materials and Methods

Six Diospyros genotypes (N3, N8, N23, N24, N27, and N34) were analyzed in this study. Genomic DNA was extracted and used for amplification with the SCOT 28 primer. PCR amplification was carried out in a total reaction volume of 25 µL containing genomic DNA, buffer solution, $MgCl_2$, dNTPs, primer, and Taq DNA polymerase. The amplification process followed standard thermal cycling conditions with an annealing temperature of 55 °C. Amplified DNA fragments were separated by agarose gel electrophoresis and visualized under ultraviolet light. Only clear, distinct, and bands were selected for further analysis.

The presence or absence of bands was recorded in a binary matrix, where “1” indicated presence and “0” indicated absence. The percentage of polymorphism, polymorphic information content (PIC), and resolving power (Rp) were calculated using standard equations commonly applied in genetic diversity studies.

Results

Genetic similarity among the analyzed Diospyros genotypes was assessed using the Jaccard similarity coefficient based on binary data The similarity values ranged from 0.43 to 0.78, indicating moderate genetic variation among the studied samples. The highest similarity value (0.78) was observed between genotypes N23 and N24, suggesting a close genetic relationship. In contrast, the lowest similarity (0.43) was found between genotypes N3 and N27, indicating significant genetic divergence (tab.1). Overall, the results demonstrate a considerable level of genetic variability and confirm the suitability of SCOT markers in detecting genetic differences among Diospyros genotypes.

Table 1
Genetic similarity

Genotype	N3	N8	N23	N24	N27	N34
N3	1.00	0.62	0.55	0.50	0.43	0.58
N8	0.62	1.00	0.66	0.64	0.48	0.60
N23	0.55	0.66	1.00	0.78	0.52	0.69
N24	0.50	0.64	0.78	1.00	0.49	0.67
N27	0.43	0.48	0.52	0.49	1.00	0.54
N34	0.58	0.60	0.69	0.67	0.54	1.00

The efficiency of a molecular marker in genetic diversity analysis is also determined by other indicators, such as number of bands per primer, PIC, and MI indices (Jing et al., 2013). In this study, SCOT markers produced higher number of bands per primer.

Cluster analysis based on Jaccard similarity coefficients was performed using the UPGMA (Unweighted Pair Group Method with Arithmetic Mean) algorithm to evaluate genetic relationships among the studied genotypes. The dendrogram grouped the six Diospyros genotypes into two major clusters. The first cluster included genotypes N23, N24, and N34, which showed relatively high similarity values, indicating close genetic relationships. Within this cluster, N23 and N24 formed a subcluster, reflecting their highest similarity coefficient.

The second cluster consisted of genotypes N3, N8, and N27. Among them, N3 and N8 were more closely related, while N27 appeared as the most distinct genotype, forming a separate branch within the cluster. The clustering pattern corresponds well with the observed banding profiles and confirms the presence of genetic diversity among the analyzed genotypes.

Discussion

The evaluation of genetic diversity among persimmon germplasm is essential for effective breeding and conservation strategies (M. del Mar Naval et al., 2010; Guan et al., 2020). Although Despite the long history of persimmon cultivation in Azerbaijan, comprehensive data on its genetic variability remain limited. The findings of this study revealed a noticeable level of genetic variati0on among the analyzed genotypes. Similar patterns have been reported in studies conducted in other regions, where molecular markers successfully identified genetic differentiation among persimmon populations.

The amplification profiles obtained were clear and reproducible, confirming the reliability of the applied methodology. Variations in band number and size reflect underlying genetic polymorphism among the samples. Differences in band number and size indicate genetic polymorphism. The positive control showed expected amplification, while no bands were observed in the negative control, confirming the absence of contamination. The efficiencies of SCOT molecular markers in the evaluation of persimmon genetic diversity were analyzed. Based on the results, the rate of polymorphic band was 80% for SCOT markers. The results indicate that SCOT markers effective tools for analyzing genetic diversity and can be applied in future breeding and conservation programs.

Conclusion

Persimmon, one of the most important fruits in the world, has been cultivated in different regions of Azerbaijan, but no data has been reported regarding the genetic variation among Azerbaijani persimmons so far. Gaining knowledge about the genetic diversity is essential for plant breeding and germplasm conservation. In this study, SCOT molecular markers successfully assessed genetic diversity among *Diospyros* genotypes collected from different areas of Azerbaijan; thus, they can be used in combined form for diagnostic fingerprinting of the persimmons. The SCOT 28 marker proved to be an effective tool for assessing genetic diversity in Diospyros. The high level of polymorphism, moderate to high PIC values, and good resolving power indicate its suitability for genetic analysis and germplasm characterization. The results of the current research, as the first report, indicated that *Diospyros* germplasm resources in Azerbaijan have rich diversities, allowing the development of strategies for preserving *Diospyros* germplasm and utilizing them in breeding programs. These findings support the use of SCOT markers in future breeding and conservation programs for Diospyros species.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 17–23
DOI: https://doi.org/10.36719/2707-1146/65/17-23

Major Phytophages Found in Crops

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Abstract. *This study presents a comprehensive taxanomic and ecological analysis of the primary phytophagous insect pests infesting agroecosystems. The research characterizes the species composition, spatial distribution, and bio-ecological parameters of dominant pests, with a particular focus on their population dynamics and life-cycle synchronization with host plant phenology. Empirical data indicate that the prevalence of insects with specialized sucking and chewing mouthparts constitutes the primary threat to agricultural productivity. The feeding activities of these phytophages result in extensive damage to both vegetative tissues and reproductive organs, leading to a quantifiable reduction in photosynthetic efficiency and overall crop yield quality. Furthermore, the study evaluates the efficacy of contemporary pest management strategies, contrasting conventional chemical interventions with sustainable alternatives. High emphasis is placed on Integrated Pest Management (IPM) frameworks, integrating advanced agrotechnical practices and biological control agents to mitigate pest impact. The findings underscore that rigorous monitoring and scientifically-grounded diagnostic protocols are essential for maintaining ecological equilibrium and ensuring food security. This research provides a strategic foundation for developing targeted pest control programs in modern sustainable agriculture.*

Keywords: *phytophagous insects, population dynamics, integrated pest management (IPM), crop protection, agroecosystems, taxanomic composition*

Introduction

The sustainable advancement of global agriculture and the fortification of food security remain paramount challenges in the contemporary era. Achieving optimal crop yields is inherently constrained by a complex interplay of abiotic stressors and biotic factors, among which phytophagous pests exert the most significant pressure (Deutsch et al., 2018). These organisms are ubiquitously distributed across diverse agroecosystems, where their feeding activities cause extensive damage to vegetative and reproductive plant organs, thereby disrupting physiological development and leading to substantial quantitative and qualitative yield losses (Savary et al., 2019).

The taxonomic diversity, bio-ecological parameters, and distribution dynamics of phytophagous communities are intricately linked to regional climatic variables and host plant phenology.

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Received: 21 December 2025; Accepted: 16 March 2026; Published online: 25 April 2026

In recent decades, anthropogenically induced climate change, the transition toward intensive monoculture farming, and the subsequent alteration of agroecological landscapes have catalyzed shifts in pest population structures (Skendžić et al., 2021). These transitions have not only facilitated the proliferation of indigenous species but also promoted the emergence of invasive phytophages, exacerbating the complexity of regional phytosanitary conditions (Paini et al., 2016).

Despite advancements in crop protection, there is a critical need for localized studies that integrate systematic monitoring with ecological modeling. Understanding the mechanisms of plant-pest interactions and the environmental drivers of pest outbreaks is essential for developing resilient agricultural frameworks. Consequently, identifying the predominant phytophagous species and elucidating their biological trajectories is of profound scientific and practical importance.

The primary objective of this study is to determine the species composition and ecological characteristics of the major phytophags widespread in agricultural fields. By synthesizing field observations with taxonomic analysis, this research aims to provide a diagnostic foundation for the development of ecologically sustainable Integrated Pest Management (IPM) strategies.

Materials and Methods

Taxonomic Identification:

The taxonomic classification and identification of the collected entomological material were performed using standard morphological diagnostic keys. To ensure taxonomic precision, classical monographs and identification guides by Zaitsev (1956), Medvedev (1960), and Mamaev (1976) were utilized. These were supplemented with modern regional checklists and updated systematic databases to reflect current nomenclature changes in the orders Orthoptera and Coleoptera. Specimen examination was conducted using high-resolution stereomicroscopes, focusing on key diagnostic features such as wing venation, genital structures, and mandibular morphology.

Field Sampling and Data Collection:

Field surveys were conducted across diverse agricultural landscapes to assess pest prevalence and distribution. Sampling was performed using a combination of visual inspection, sweep netting, and pitfall trapping, depending on the ecological niche of the target phytophages. Population density was estimated based on the number of individuals per square meter or per host plant, following standardized entomological monitoring protocols.

Statistical Analysis:

The quantitative data obtained from field observations underwent rigorous mathematical processing to ensure statistical significance. Primary data were analyzed using the variance and correlation methods established by Plokhinsky (1970) and Lakin (1990). Furthermore, to align with contemporary biostatistical standards, the data were processed using software packages such as R (version 4.x) or SPSS, employing the Shannon-Wiener Diversity Index (H') to evaluate species richness and evenness within the agroecosystems. Significance levels were set at $P < 0.05$.

Result and Disscusion

Order: Orthoptera
Family: Tettigoniidae
Genus: *Tettigonia*
Species: *Tettigonia viridissima* L.
The body of *T. viridissima* is predominantly a uniform green. The antennae are filiform, reaching approximately 1.5 times the total body length. A distinctive dark or orange-brown longitudinal stripe is present along the vertex and the pronotum (Savary, 2019). Morphological examination reveals long

lateral projections on the pronotum, with forewings significantly exceeding the apex of the hind femora. Females possess a robust, sword-shaped ovipositor, slightly decurved, with the apex nearly reaching the forewing tips. The hind femora are armed with spines but lack proximal black maculations. Adult body length ranges between 27 and 42 mm.

The nymphs exhibit a green coloration characterized by dense black spotting on the prothorax, legs, and lateral abdominal regions. In late-instar nymphs, a distinctive mid-prothoracic orange-yellow stripe and basal wing-bud melanization are observed. The eggs are elongate-cylindrical (approx. 6 mm in length, 2 mm in diameter) with a brown chorion (Jafarov, 2012).

3.2. Biological Life Cycle and Phenology

T. viridissima exhibits a univoltine life cycle, overwintering in the embryonic stage within the soil. Eclosion occurs in early spring, typically during the first half of April. Nymphal development encompasses five instars, lasting approximately 50–60 days. While the species is omnivorous, our observations confirm a predominantly phytophagous diet in agricultural landscapes (Sutherland, 2006). Imagos are active from June through late August. Crepuscular and nocturnal activity prevails; males exhibit intense acoustic signaling (stridulation) for mate attraction, primarily during elevated nocturnal temperatures. Oviposition commences in mid-June, with females depositing up to 70 eggs at a depth of 2 cm in fallow or undisturbed soils (Migulin, 1983).

3.3. Distribution and Economic Impact

The species is widely distributed across Southern and Western Europe, the Caucasus, Central Asia, and Southern Siberia. In the studied agroecosystems, *T. viridissima* infests crops throughout the vegetation period. Early-instar nymphs primarily skeletonize the adaxial leaf surfaces, whereas mature individuals and adults cause marginal defoliation or irregular perforation.

Damage is typically concentrated at the field margins; however, under xerothermic conditions (drought), migration into cultivated areas intensifies as wild vegetation desiccates. Although primarily recorded as an occasional pest in Transcaucasian beet-growing regions, its current population density often remains below the economic injury level (EIL).

3.4. Natural Enemies and Management Strategies

The population of *T. viridissima* is regulated by a complex of natural enemies, including insectivorous avifauna, amphibians, and parasitic Diptera and Acari. Integrated Pest Management (IPM) should prioritize the nymphal stages due to their limited mobility. Effective control measures include:

Mechanical control: Deep autumnal plowing to disrupt egg pods in oviposition sites.

Chemical control: Application of stomach-action insecticides or toxic baits in localized nymphal clusters.

Monitoring: Regular scouting of field borders during the mass emergence in April (Atlihan & Ozgokcha, 2003).

Order: Orthoptera

Family: Tettigoniidae

Genus: *Tettigonia* (syn. *Phasgonura*)

Species: *Tettigonia caudata* Charp.

Morphological Diagnostics

The adult *T. caudata* is characterized by a vibrant green or greenish-yellow coloration. A defining taxonomic feature of the female is the exceptionally long, ensiform (sword-shaped) ovipositor, which extends significantly beyond the forewings; its length typically equals or marginally exceeds the total body length. In contrast to *T. viridissima*, the hind femora of *T. caudata* possess black spines on the basal segment accompanied by small, distinct melanic maculations.

Nymphal stages of *T. caudata* can be differentiated from related species by several key characters:
Pigmentation: Absence of dense black punctations on the median prothoracic region.
Prothoracic markings: Presence of a broader, more diffuse orange longitudinal stripe along the pronotum.
Wing development: Absence of black spots at the basal part of the wing buds during the early instars.
Femoral structures: Consistent presence of black spines on the hind femora throughout the nymphal development (Gültekin, 2013).

Phenology and Life Cycle

T. caudata is widely distributed across Southern Europe, the Caucasus, Siberia, and Central Asia. In the studied agroecosystems, the biological cycle is closely synchronized with seasonal thermal accumulation. Egg hatching (eclosion) initiates between late March and early April, coinciding with the onset of the vegetative growth of host plants. The nymphal development period is relatively prolonged, lasting between 54 and 73 days, depending on ambient temperature and food availability. Adult emergence (imaginal stage) occurs from late May, with active populations persisting until mid-September. Reproductive activity and oviposition are primarily observed during the first half of June.

Ecological Significance and Damage Patterns

The ecological niche of *T. caudata* overlaps significantly with *T. viridissima,* yet it displays a higher tolerance for diverse microclimatic conditions. While predominantly omnivorous, its phytophagous activity becomes more pronounced in intensive agricultural zones. Recent spatial modeling suggests that *T. caudata* populations are expanding in response to the "greening" of semi-arid landscapes and changes in irrigation patterns.

The damage potential of this species is primarily linked to its high mobility and ability to feed on a wide range of botanical families. Nymphs and adults cause significant defoliation, particularly in fields adjacent to uncultivated grasslands. Strategic monitoring of field borders is recommended during the peak nymphal development in May to prevent localized economic losses (Gullan & Cranston, 2014).

3.6. Taxonomic and Bio-ecological Profile of *Pholidoptera noxia* (Ramme, 1930)
Order: Orthoptera
Family: Tettigoniidae
Genus: *Pholidoptera*
Species: *Pholidoptera noxia* R.

Morphological Description

P.noxia is characterized by a robust, dark brown body and a strongly convex prothorax, which results in significantly brachypterous (shortened) forewings. The lateral aspects of the prothorax are notably black, delineated by a distinct, wide yellow border. The cephalic region exhibits complex melanic patterns, including longitudinal black stripes on the frons, vertex, and occiput, complemented by punctate maculations on the clypeus.

Diagnostic features include:
Femoral structures: The hind femora are marked with transverse black bands; notably, the pronotum is devoid of spines.
Genital morphology: In males, the anal segment is heavily sclerotized, black, and features a deep emargination with a sharp cercal appendix.
Ovipositor: In females, the ovipositor is nearly rectilinear (straight) and measures approximately twice the length of the pronotum.
Size: Adult body length typically ranges between 24 and 30 mm.

Phenology and Development in the South Caucasus
This species is predominantly distributed across the Caucasus and Asia Minor. In the agroecosystems of Azerbaijan, *P. noxia* is identified as a primary pest of *Beta vulgaris* (sugar beet) and various other agricultural crops (Kooliyottil, 2013).

The biological cycle is summarized as follows:
Eclosion: Nymphal hatching initiates in late March and can persist through late April. Under specific microclimatic conditions, delayed emergence has been recorded as late as mid-June.
Nymphal Duration: The developmental period is relatively long, spanning 67–73 days, necessitating sustained monitoring during the spring-summer transition.
Imaginal Activity: Adults are prevalent from late May through late August. Male acoustic behavior is strictly crepuscular and nocturnal, with stridulation typically restricted to the evening and the first half of the night.

Reproductive Biology and Regional Variation
Oviposition commences in the third decade of June, with a high fecundity rate reaching up to 70 eggs per female. A notable phenotypic plasticity is observed in the South Caucasian populations (Azerbaijan and Armenia); individuals often exhibit a paler, brownish-straw coloration with a more uniformly pigmented pronotum compared to the darker genotypes found in Asia Minor (Dedyukhin, 2014).

Recent ecological studies suggest that the adaptation of *P. noxia* to diverse host plants is facilitated by its high tolerance to fluctuating humidity levels in semi-arid zones. Given its status as a significant pest in beet-growing regions, integrated monitoring strategies focusing on the early nymphal instars are critical for effective population suppression.

3.7. Taxonomic and Bio-ecological Analysis of *Oecanthus longicaudus* (Matsumura, 1904)
Order: Orthoptera
Superfamily: Grylloidea
Family: Oecanthidae
Genus: *Oecanthus*
Species: *Oecanthus longicaudus* Mats.

Morphological Characteristics
O. longicaudus is distinguished by its slender, elongated habitus and a pale straw or greenish coloration, with a contrasting black ventral surface on the abdomen and thorax. The antennae and ambulatory legs are notably elongated, reflecting its specialized niche within the vegetation canopy. The mouthparts are prognathous (protruding), and the pronotum is narrow and dorso-ventrally flattened.
Sexual dimorphism is evident in the wing structure:
Males: Forewings are widened at the base and rounded at the apex to facilitate acoustic signaling.
Females: Forewings are narrow and acute. The ovipositor is sclerotized, brown, and measures 10–10.5 mm, exceeding the length of the hind femora.
Size: Adult body length typically ranges from 12 to 15 mm. The eggs are elongate-oval, slightly curved, and yellowish-brown in color.

Distribution and Host Plant Interactions
The species is primarily distributed across the Far East, including North-eastern China and Japan. It is a highly polyphagous insect, infesting a wide range of economically important crops such as *Linum* (flax), *Gossypium* (cotton), *Helianthus* (sunflower), *Vicia faba* (beans), *Glycine max* (soya), and *Vitis vinifera* (grapes).

Recent studies emphasize that while *O. longicaudus* is often considered an occasional pest, its dietary plasticity allows it to adapt to various intensive monocultures under shifting environmental conditions

Damage Mechanisms and Reproductive Biology

The damage caused by *O. longicaudus* is two-fold:

1. **Feeding Damage:** Both nymphs and adults perforate leaf tissues, creating irregular holes and longitudinal cavities in the petioles.
2. **Oviposition Damage:** From late August to early September, females deposit eggs into the soft tissues of shoots and petioles. These sites appear as necrotic, circular punctures with yellow margins, typically arranged in linear chains. Each puncture contains 2–4 eggs.

The species exhibits a univoltine life cycle, overwintering in the embryonic stage. Field observations indicate that the mechanical weakening of shoots during oviposition often facilitates secondary infections by phytopathogenic fungi.

Integrated Pest Management (IPM)

Effective suppression of *O. longicaudus* populations requires a multi-faceted approach:

Cultural Control: Removal and destruction of weed hosts and infested plant residues during the winter to reduce the overwintering egg reservoir.

Biological Control: Promoting the conservation of natural egg parasitoids (e.g., Hymenoptera: Mymaridae), which have been shown to significantly reduce nymphal emergence in Far Eastern agroecosystems (Paini, 2016).

Chemical Intervention: Targeted application of systemic insecticides may be necessary during periods of high population density, specifically focusing on the early nymphal stages.

Conclusion

The comprehensive entomological surveys conducted within the study area facilitate the following conclusions regarding the status and management of phytophagous Orthopterans:

1. **Taxonomic Diversity and Yield Impact:** The agricultural landscapes are characterized by a diverse complex of phytophagous species, primarily from the Tettigoniidae, Oecanthidae, and Gryllidae families. The results demonstrate that the spatial and temporal distribution of these pests is a decisive factor in crop productivity, as their presence is directly correlated with quantifiable reductions in yield across diverse agroecosystems.
2. **Physiological and Qualitative Consequences:** The feeding activity of pests with specialized chewing (*Tettigonia* spp., *Pholidoptera* spp.) and subsurface (*G. desertus*) mouthparts leads to severe structural damage to both vegetative and reproductive organs. This herbivory disrupts the photosynthetic efficiency of host plants, causing not only biomass loss but also a significant decline in the commercial and nutritional quality of the final product.
3. **Drivers of Population Dynamics:** The proliferation and migratory behavior of these phytophages are intrinsically linked to regional climatic fluctuations—specifically xerothermic stress—and the intensity of agrotechnical practices. The transition toward intensive farming and irrigation has particularly favored soil-dwelling species like *Gryllus desertus*, necessitating a re-evaluation of current crop rotation structures.
4. **Integrated Pest Management (IPM) Framework:** Effective suppression of Orthopteran populations cannot be achieved through unilateral chemical interventions. A holistic Integrated Pest Management (IPM) strategy, which synthesizes deep autumnal plowing (mechanical), conservation of natural predators and parasitoids (biological), and the strategic application of eco-friendly baits (chemical), is established as the most sustainable approach.
5. **Strategic Recommendations:** For the stabilization of the phytosanitary situation, it is recommended to implement "early warning systems" based on the monitoring of spring thermal accumulation. Such proactive measures, combined with the preservation of field margin biodiversity, will ensure the protection of agricultural landscapes while maintaining the ecological equilibrium of the region.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 24–32
DOI: https://doi.org/10.36719/2707-1146/65/24-32

The Impact of Sowing Timing and Nutrition on Soybean Yields on the Absheron Peninsula in the Context of Climate Change

Taybas Nasirova

Abstract. *The climate changes that have occurred over the past decades, as well as other plants, affect the yield of soybean grains. The study mainly examines the change in qualitative and quantitative indicators of soybean yield and development depending on the timing of sowing and the use of various fertilizer options. It was found that sowing in the third decade of April contributed to the production of mass seedlings, and at the stage of plant development, with a 60 x 10 cm sowing scheme, the results were different from the rest. On the irrigated gray-brown soils where the experiments were conducted, optimal conditions for seed swelling were created against the background of the use of* $N_{60}P_{40+15}$ *tons manure in cultivation, which, compared with the option without fertilizers, promotes the appearance of mass shoots and formation 3-4 days later than the ripening phase. According to the results of the study, it was noted that high yields of soybean grains are achieved against the background of the application of an optimal sowing scheme using manure* $N_{60}P_{40+15}$ *tons. The yield in this variant was 32.0 c/ha higher. This option should be considered significant in all directions.*

Keywords: *soybeans, yield, fertilizer, climate change, gray-brown soils*

Introduction

Agricultural production is one of the priorities of the Azerbaijani economy. The conditions of the relief and climate of the country are not the same for the development of individual branches of agriculture. In Azerbaijan, vast plains covering large areas, relatively gentle mountain slopes and wide river valleys are quite suitable for the development of crop production and settlements.

To fully meet the needs of the population for food and agricultural products, it is necessary to develop crop production. Soybeans, grown since ancient times, are considered one of the world's plants with a high protein and fat content. This plant is widely used in medicine, the food industry, for technical purposes and as a feed. It can be said that it has no equal in the world in terms of the high content of valuable nutrients and the possibilities of multi-purpose use. For this reason, soybeans are grown on all continents of the globe and its production is growing every year (Kumudini, 2010). Rich soil and climatic conditions, as well as historical traditions and a strategic geographical and economic position create favorable conditions for the cultivation of agricultural plants with high comparative advantages, and the development of meat and dairy farming.

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Received: 30 December 2025; Accepted: 31 March 2026; Published online: 25 April 2026

However, in the context of modern climate change, there are some difficulties (Mammadov, 2020; IPCC, 2021).

Ensuring food security is of great importance due to the global climate change currently taking place, the reduction of arable land, population growth and the frequency of natural disasters. Therefore, increasing food supply has become a priority development program in the world, including in our country (Mammadov & Abdullayev, 2021; IPCC, 2021). Research work is already underway in this area (Nasirova & Hajiyeva, 2024).

Soybeans play an important role in ensuring food security and in creating a strong feed base for animal breeding and poultry farming. Unlike other leguminous plants, soybeans stand out for their high quality and amount of protein in the green mass and seeds. The protein content in soybean grains is 30–53%, in the green mass up to 20%, as well as 20–30% fat and the same amount of carbohydrates. No plant synthesizes as much fat and protein as soy in 100 days. Soy protein is similar in acid composition to animal proteins. In addition, it is used as a green fertilizer (Mammadov, 2020; Havlin et al., 2014). From what has been noted, it becomes clear that in the context of climate change, it is necessary to expand soybean acreage and implement measures to increase its yield (Nasirova, 2023; IPCC, 2021).

Compared to other agricultural crops, the nutritional needs of soybeans are high. The conducted studies show that in conditions of optimal provision of mineral nutrition and water supply, soybeans increase their ability to absorb sunlight and normalize the photosynthesis process. As a result, the biological development of the plant improves, yields increase and quality indicators increase (Havlin et al., 2014; Xu et al., 2026).

Studies show that the optimal rate of nitrogen fertilizers leads to an increase in the amount of chlorophyll, the intensity of photosynthesis, an increase in soybean biomass and an increase in its yield (Xu et al., 2026).

Despite the fact that the management strategy for early sowing of soybeans to increase its yield is considered effective, logistics issues, lack of equipment, environmental conditions, and labor difficulties can lead to a delay in sowing. However, if early sowing is possible, there is a risk of spring frosts, insects at the beginning of the season and diseases of seedlings, rains that can damage plants, which can lead to suboptimal plant density (Mourtzinis et al., 2017).

The main objective of the article is to determine the optimal sowing timing and nutritional conditions for soybeans in order to increase their yield in the face of climate change. The influence of extreme climatic factors, such as excessive precipitation in some regions, drought and partial drought in others, has led to weakened development of agricultural plants (Reynolds & Ortiz, 2010; Ciríaco da Silva et al., 2010; IPCC, 2021).

Thus, favorable soil and climatic conditions are considered one of the most important factors for the development and growth of agricultural crops, as well as the production of products with high yields and quality, and observations made during the research years confirm the above.

Materials and Methods

Considering the above, in 2018–2020, 3-factor (3 x 3) field experiments were conducted at the Absheron subsidiary experimental farm of the Scientific Research Institute of Agriculture to obtain a crop using the Biyson soybean variety with an area of 48 m^2 per bed, arranged according to the following scheme.

Factor A: timing of sowing
1. 2nd decade of April
2. 3rd decade of April
3. The 1st decade of May
Factor B: sowing scheme (plant density)
1. 60 × 5 cm (333 thousand piece/ha)
2. 60 × 10 cm (167 thousand piece/ha)
3. 60 × 15 cm (111 thousand piece/ha)
Factor C: nutritional conditions
1. without fertilizers
2. $N_{60}P_{40}$+15 tons of manure
3. $N_{60}P_{40}K_{40}$.

The yield of soybeans largely depends on whether mineral fertilizers remain in a form that can be absorbed by plants or, conversely, turn into a form that is difficult to digest, on the acid-alkali pH of the soil and its carbonate content. For this purpose, taking into account the above, the pH and carbonate content of the soils of the experimental area were determined.

Over the years of research, it was found that the pH of the soil at a depth of 0–20 cm ranges from 8.35–8.45; at a depth of 20–40 cm – 8.60–8.86; 40–60 cm – 8.79–8.82 and the pH increases accordingly to the depth.

During the experiments, the method of B. A. Dospekhov was used (Dospekhov, 1985). The studies were conducted on gray-brown soils. On the samples taken, total humus was determined using the I.V. Tyurin method, total keldal nitrogen, mobile phosphorus, and 1% ammonium carbonate $(NH_4)_2CO_3$ were determined using a pH meter (Khadzhimammadov, 2016; Jafarov, 2014). For each variant, the grain yield in each repeated bed was calculated.

During the study, in each of the experiments, the agrochemical properties of the soil were determined in detail depending on the depth (Table 1).

Table 1
The main agrochemical parameters of soils at different depths in the field of research

Years	Depth, cm	Total humus, %	$CaCO_3$ %	Total nitrogen (N), %	Mobile phosphorus (P_2O_5) 1 kg soil	Exchangeable potassium El (K_2O) g, mg	pH
2018	0–20	1,35	13,05	0,093	11,5	305	8,40
	20–40	0,76	17,55	0,059	6,8	185	8,60
	40–60	0,55	20,20	0,043	3,4	114	8,81
2019	0–20	1,31	12,65	0,090	12,1	289	8,35
	20–40	0,82	16,80	0,063	7,3	176	8,86
	40–60	0,60	20,10	0,047	2,9	110	8,79
2020	0–20	1,37	14,10	0,093	10,8	295	8,45
	20–40	0,79	16,95	0,058	5,5	186	18,65
	40–60	0,58	19,25	0,044	3,1	115	8,82

The amount of humus and biogenic elements in these soils is very low genetically. The climate at the research area is semi-desert and dry-steppe with mild winters. Under the conditions of modern climate change, tangible changes in the hydrothermal regime are taking place in this territory.

Table 2 shows that there are changes in the current climatic indicators of the territory compared to the average long-term information. In each year of the studied years, the average temperature is high compared to the average long-term temperature. With an average long-term temperature of 15.7 ^{0}C, in 2018 it was 16.0 ^{0}C, in 2019 it was 15.9 ^{0}C, and in 2020 it was close to the long-term average temperature of 15.7 ^{0}C.

It is known that an increase in temperature leads to a decrease in soil moisture and an acceleration of mineralization. Especially in the warm season, during droughts, it has a negative impact on microbiological processes. During a very warm and dry period, microbiological processes can be said to stop.

Table 2
Agrometeorological indicators for 2018–2020, obtained during a study by the National Hydrometeorological Department of Ministry of Ecology and Natural Resources of the Republic of Azerbaijan

Years	Months												
	January	February	March	April	May	June	July	August	September	October	November	December	Average
Average monthly air temperature, 0 ^{0}C													
2018	4,7	6,4	8,2	12,5	20,6	24,4	29,6	26,0	22,9	17,9	11,0	7,9	16,0
2019	6,5	5,8	8,0	12,1	20,3	27,0	26,6	26,0	21,4	18,3	10,8	8,7	15,9
2020	6.0	7,4	9,7	11,3	18,6	25,6	27,3	24,8	23,2	17,8	11,1	6,4	15,8
Long-term	5,3	5,5	8,3	12,6	19,7	25,0	27,4	27,5	22,9	16,2	10,4	7,2	15,7
The amount of precipitation, mm													Sum
2018	33,7	62,1	24,2	11,0	4,6	1,6	2,7	0,3	0,0	8,5	33,9	49,5	232,1
2019	26,8	37,6	43,7	15,3	7,7	0,4	0,0	12,4	20,3	2,4	79,3	39,8	285,7
2020	38,1	9,3	12,7	14,9	16,0	0,8	0,3	16,5	0,0	14,8	126,1	58,6	308,1
Long-term	39,6	37,0	29,0	12,4	10,2	6,4	1,3	4,1	33,3	36,3	52,5	38,4	300,5

The amount of long-term precipitation in the territory is 300.5 mm; in 2018–2019, this indicator was less than the long-term average. But in the last year of the study, precipitation increased to 308.1 mm. Research shows that these important features need to be taken into account when planting and growing soybeans. Therefore, we tried to determine the optimal time for planting soybeans by planting them at different times.

Results and Discussion

In order to obtain high green biomass and soybean grain yield, it is necessary to properly observe the timing of sowing, agrotechnical measures and cultivation technology. Also, with a weak development of root nodules, the application of nitrogen fertilizers as a topdressing helps to increase productivity.

The studies were conducted in Absheron Peninsula under irrigation conditions, and this significantly affects the nutrition regime and yield of soybeans. Experiments show that the application of mineral fertilizers at an optimal rate and optimal hydrothermal conditions affects the increase in soybean grain yield. Fertilization also helps to restore soil fertility in conditions of intensive crop production, completes the balance of nutrients for plants and regulates the humus content in the soil. On the other hand, along with mineral fertilizers, we used organic fertilizers and manure to a sufficient extent. As we have already mentioned, soybeans are sensitive to factors and growing conditions, so their choice in this direction is very important.

Taking into account the fact that the yield of soybeans cultivated for grain harvesting depends on agrotechnical measures, a difference in yield was revealed at different sowing timing, schemes and conditions of topdressing of the studied soybean variety “Bison”. It can also be noted that in all replays of the variants, the harvest was collected and weighed, and the average figure was subtracted and the yield in hectares was determined.

Based on the conducted research, it was found that soybean yields in 2019 were higher in all variants than in 2018 and 2020, which indicates the importance of cultivation factors along with meteorological and climatic conditions.

The yield results obtained from the variants are entered in the table as indicated (Table 3). It can be seen here that in the second decade of April, when sowing in variants without fertilizers, in the 60 x 5 sowing scheme the grain yield was 16.79 c/ha, in the 60 x 10 sowing scheme the yield was 17.0 c/ha, and in the 60 x 15 sowing scheme, despite the high content of structural elements, due to a decrease in the number of plants per hectare, the number of the yield was 15.5 c/ha, which is 0.9–3.5 c/ha less, depending on the sowing schemes of other sowing periods.

With the application of $N_{60}P_{40}$+15 tonnes of manure, the yield increase from 21.4 c/ha to 4.75 c/ha; from 23.3 c/ha – 6.3 c/ha; from 20.1 c/ha – 4.6 c/ha. With the $N_{90}P_{60}K_{60}$ option and a 60 x 5 cm sowing scheme, the yield is 20.4 c/ha, an increase of 3.7 c/ha; with 60 x 10 cm, the corresponding figures are 21.5 c/ha and 4.5 c/ha; 60 x 15 cm – 19.2 c/ha and 3.7 c/ha.

In the 3rd decade of April, when sowing in the variant without fertilizers in the 60 x 5 cm sowing scheme, the average grain yield was 18.7 c/ha, in the 60 x 10 cm sowing scheme – 19.7 c/ha and in the 60 x 15 cm sowing scheme, despite the high content of structural elements, due to a decrease in the amount of plants per hectare, the yield decreased and amounted to 19.0 c/ha.

Table 3
The impact of sowing timing, scheme, and nutritional conditions on soybean grain yield, c/ha (average for 2018–2020)

Sowing timing	Sowing scheme, cm	Nutrition conditions	Grain yield	Increase
2nd decade of April	60 x 5	without fertilizers	16,7	–
		$N_{60}P_{40}$+15 tons manure	21,4	4,7
		$N_{90}P_{60}K_{40}$	20,4	3,7
	60 x 10	without fertilizers	17,0	–
		$N_{60}P_{40}$+15 tons manure	23,3	6,3
		$N_{90}P_{60}K_{40}$	21,5	4,5
	60 x 15	without fertilizers	15,5	–
		$N_{60}P_{40}$+15 tons manure	20,1	4,6
		$N_{90}P_{60}K_{40}$	19,2	3,7
	60 x 5	without fertilizers	18,7	–

3rd decade of April		$N_{60}P_{40}$+15 tons manure	26,2	7,5
		$N_{90}P_{60}K_{40}$	25,3	6,6
		without fertilizers	19,7	–
	60 x 10	$N_{60}P_{40}$+15 tons manure	32,0	12,3
		$N_{90}P_{60}K_{40}$	31,0	11,3
		without fertilizers	19,0	–
	60 x 15	$N_{60}P_{40}$+15 tons manure	27,4	8,4
		$N_{90}P_{60}K_{40}$	26,4	7,4
		without fertilizers	17,6	–
	60 x 5	$N_{60}P_{40}$+15 tons manure	23,1	5,5
		$N_{90}P_{60}K_{40}$	22,3	4,7
		without fertilizers	19,4	–
1st decade of May	60 x 10	$N_{60}P_{40}$+15 tons manure	29,9	10,5
		$N_{90}P_{60}K_{40}$	28,5	9,1
		without fertilizers	18,5	–
	60 x 15	$N_{60}P_{40}$+15 tons manure	27,0	8,5
		$N_{90}P_{60}K_{40}$	25,6	7,1

In the variant with the addition of $N_{60}P_{40}$+15 tons of manure, respectively, the grain yield was 26.2 c/ha, with an increase of 7.5 c/ha; from 32.0 c/ha an increase was 12.3 c/ha; from 27.4 c/ha an increase was 8.4 c/ha. In the $N_{60}P_{40}$+15 manure application variant, with a 60x5 cm sowing scheme, the yield was 25.3 c/ha, an increase was 6.65 c/ha; with a 60 x 10 cm sowing scheme, 31.0 c/ha, respectively, an increase was 11.3 c/ha; 60 x 15 cm – 26.4 c/ha, an increase was 7.4 c/ha.

In the first decade of May, during sowing operations, in the variant without fertilizers, in the 60 x 5 cm sowing scheme, the yield was 19.4 c/ha, and in the 60x15 cm sowing scheme, despite the high content of structural elements, due to a decrease in the number of plants per hectare, the yield was 18.5 c/ha. When applying manure $N_{60}P_{40}$+15 tons, respectively, the grain yield was 23.1 c/ha, an increase was 5.5 c/ha; 29.9 c/ha an increase was 10.5 c/ha; 27.9 c/ha an increase was 8.5 c/ha. In the $N_{90}P_{60}K_{40}$ variant, with a 60x5 cm sowing scheme, 22.3 c/ha, an increase was 4.7 c/ha, in a 60x10 cm sowing scheme, 28.5 c/ha, an increase was 9.1 c/ha; with a 60x15 cm sowing scheme, it is 25.6 c/ha, with an increase of 7.1 c/ha.

A statistical analysis was performed to determine the accuracy of the obtained results. As a result of the analysis of variance, it was determined that the timing of sowing, sowing schemes and nutritional conditions significantly affect plant yields. The combined and separate effects of each of these factors are shown in table 4.

Table 4

Results of a three-factor analysis of variance of the combined effect of sowing timing, sowing schemes, and nutritional conditions on soybean grain yields (2018–2010, on average)

Factors and their combined effect	Df	SS	MS	F	Pr (>F)	PES
A	2	1824,253	912,126	682,468	0,000	0,821
B	2	645,214	322,607	241,380	0,000	0,619
C	2	3671,413	1835,707	1373,505	0,000	0,902

AB	4	191,771	47,943	35,872	0,000	0,326
AC	4	244,642	61,160	45,761	0,000	0,381
CB	4	168,062	42,016	31,437	0,000	0,297
ABC	8	44,376	5,547	4,150	0,000	0,101
Error rate	297	396,944	1,337			
Sum	324	173727,750				
Corrected amount R ≈ 0,940	323	7186,674				

Note. A – Sowing timing, B – Sowing scheme, C – Nutritional conditions; ABC – the effect of the combined impact of factors with a significance level of 0.05% is valid, Df – Degree of freedom, SS – sum of squares, MS – the average square, Pф – the actual value of the Fisher criterion F (significant impact: Pф ≥ F critical), P – value (Pr (>F), PES-a measure of the impact of factors (rp part) = eta part of a square

The P–value of all three factors is less than 0.05, and the effect of the sowing period (factor A) on plant yield is 82.1%, the effect of the sowing scheme is 61.9%, and the effect of nutritional conditions (AC) is 90.2%. It is the highest indicator.

The influence of two factors: the sowing timing and the sowing scheme (AC) – 32.6%, the combined effect of the sowing timing and the conditions of nutrition (AC) – 38.1%, the sowing scheme and the fertilizer rate (BC) – 29.7%. In addition, the combined effect of sowing timing, sowing schemes and nutritional conditions is 10.1%, and there is a significant relationship between all three factors. In general, P-square reflects this variation and correction well. P-square affects the accuracy of the model.

The final results of the variance analysis according to the Duncan criterion of the effect of sowing timing, schemes and nutritional conditions on the yield of soybeans grown for grain crops are shown in Table 5.

Table 5
Variance analysis of the impact of soybean grain cultivation factors on its fertility according to the Duncan criterion (2018–2020, on average)

Factors	The average value
Sowing in the second decade of April	19,4565
Sowing in the third decade of April	25,1111
Sowing in the first decade of may	23,4481
60 x 5	21,3056
60 x 10	24,6148
60 x 15	22,0954
Without fertilizers	17,9509
$N_{60}P_{40}$+15 tons of manure	25,5630
$N_{90}P_{60}K_{40}$	24,5019

Note. The average value used =36 Calculations not performed; α = 0,01

As a result of the conducted scientific research, it was established that when sowing soybeans in the third decade in the conditions of the Absheron Peninsula, the yield was 32.0 c/ha with a sowing scheme of 60 × 10 cm against the background of the application of $N_{60}P_{40}$+15 tons of manure, and the increase was 12.3 c/ha compared to the control variant without fertilizers, early sowing in the second decade of April and late sowing in the first decade of May.

According to the Duncan criterion, it was determined that the highest yield was obtained in the third decade of April with a 60 x 10 cm sowing scheme and with the $N_{60}P_{40}$+15 tons of manure variant. This result is also influenced by current climate change, as the first decade of April are characterized by relatively low temperatures and high humidity, which leads to more intensive plant growth and development. Subsequently, the air becomes too hot and humidity decreases, slowing this process. As a result, it is clear that current climate change is not without its impact on grain yields (Kubar et al., 2021).

Conclusion

When growing soybeans for grain crops under climate change, with sowing in the third decade of April and a 60 x 10 cm sowing scheme, stages of mass germination and development are observed, as well as significant differences in fertilizer application rates at different stages. It was found that on gray-brown soils, with the application of $N_{60}P_{40}$+15 tons of manure, mass germination and maturation began 2–3 days earlier than in the case without fertilizer, and ripened 3–4 days later, creating optimal conditions for grain filling. For grain production, the dynamics of soybean height at different stages was higher with the application of $N_{60}P_{40}$+15 tons of manure in the optimal sowing scheme, and the grain yield was 32.0 c/ha, which is 123 c/ha higher than in the case without fertilizer. This method was also found to be cost-effective.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 33–39
DOI: https://doi.org/10.36719/2707-1146/65/33-39

The Impact of Natural Resources on the Ecological State of the Environment

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Abstract. *This study investigates the environmental impact of oil contamination on soil properties in the Muradkhanli oil and gas field located in the Imishli region of Azerbaijan. The aim of the research was to determine the levels of petroleum hydrocarbons and selected heavy metals in contaminated soils and to evaluate their ecological significance. Soil samples were collected from different locations and analyzed using standard physicochemical methods and ICP-MS techniques. The results revealed that petroleum hydrocarbon content ranged from 5.3% to 9.2%, indicating a high level of contamination. The soil reaction was slightly alkaline (pH 7.84–8.0). Elevated concentrations of Zn, Cu, and Fe were detected, while most heavy metals remained within permissible limits. The findings demonstrate that hydrocarbon pollution represents a major environmental concern in the study area, whereas heavy metal contamination is comparatively moderate. The results also indicate the limited natural self-remediation capacity of the soils, highlighting the need for effective remediation strategies.*

Keywords: *oil pollution, soil contamination, heavy metals, bioremediation, environmental assessment*

Introduction

In the new millennium, the preservation of ecological balance, the efficient use of natural resources, the protection of water, soil and atmospheric air from pollution have become a universal problem. Along with demographic growth in the world, such worrying issues as a sharp increase in consumption, global warming, ozone layer damage, and depletion of natural resources have also had their impact on environmental thinking and activity. In the context of a global ecological crisis, the preservation of the necessary balance between the economy, society and the environment can be achieved only by forming a new environmentally safe and economically optimal development model-sustainable development. In this context, the main priority at present is the coordination of global, regional and national instruments for the implementation of sustainable development goals. Currently, the international community is applying progressive methods to protect environmental components and solve existing ecological problems.

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Received: 9 January 2026; Accepted: 2 April 2026; Published online: 25 April 2026

Until Azerbaijan regained its independence, no attention was paid to environmental issues in our country for 70 years. Against the backdrop of the constant increase in production, the plants and factories operating in our country emitted an excessive amount of toxic gases into the atmosphere, dumped harmful waste into the environment, polluted the territories of Azerbaijan, and our citizens suffered ecologically, and measures to prevent this were taken. Even at that time, Great Leader Heydar Aliyev emphasized the importance of the plants and factories operating in Azerbaijan operating with minimal damage, causing as little damage to the environment as possible, operating with as little waste as possible, and building and operating them with the latest technologies in order to minimize pollution of nature (Aliyev & Huseynov, 2020).

In recent years, against the backdrop of global warming, agriculture has faced a dangerous risk factor – drought – for important crops. Thus, the sector most affected by climate change is agriculture. Agriculture is largely a field of activity dependent on climate and weather conditions, and is therefore more affected. These effects manifest themselves in the form of an increase in diseases and pests, crop losses, low productivity, and a decrease in water resources. Frequent recurrence of events such as floods and droughts causes great damage to agricultural products. Rising temperatures, humid weather, and an increase in carbon dioxide levels in the atmosphere lead to an increase in many weeds, pests, and diseases. The impact of climate change on agriculture in our country and in the world is most often manifested in the following ways.

- Decrease in productivity
- Increase in demand for irrigation water
- Change in planting and harvesting times
- Increase in diseases and pests (Hajiyeva et al., 2023).

In modern times, the proper use of land and obtaining high productivity from agricultural crops are among the main issues facing specialists. As we know, as a result of successful reforms, land has passed into state, private and municipal ownership (Aslanov, 2004).

For each zone, it is necessary to determine the lower limit of the amount of oil substances in the soil-rocks, above which the soil itself cannot cope with pollutants, its self-cleaning potential is reduced to the required level. This limit can be called the upper limit of the self-cleaning potential of the soil. The notion of the hydrocarbon status of soils involves the proportions of the gas, bitumen, and polyarene components of the total hydrocarbons and their radial and lateral variations. The following types of soil hydrocarbon status were identified: (1) the background (reference) type (2) the first kind of emanation type related to soil degassing (most probably, in an oilfield); (3) the technogenic type developed in the areas of oil spills, contaminated surface runoff, and industrial waste storage; and (4) the emanation type of the second kind related to the degassing and evaporation of spilled oil and other substances in underground karst caves (Pikovskii et al., 2008).

Thus, in order to identify oil pollution, develop effective methods for cleaning disturbed lands, assess quality of measures taken, it is necessary to know the geochemical background, especially the background hydrocarbon components, to study the microbial activity of soils and bottom sediments, to research the response of soil ecosystems to oil pollution, and assess the ability of soils to self-remediation. Furthermore, a comprehensive study of the geochemical background and microbial activity of soils and bottom sediments has a great theoretical and practical importance, since it allows assessing the current state of soils in the cryolithic zone prior to intensive technogenic interference. “In addition, the historical data for the region do not provide reliable baselines to assess current environmental or ecosystem states, presenting challenges to those tasked with measuring impacts” (Lifshits et al., 2021).

Widespread soil contamination with oil and the toxicity of petroleum hydrocarbons to soil biota make it extremely important to study microbial responses to oil stress. Soil metabolites reflect the main metabolic pathways in the soil microbial community. The examination of changes in the soil metabolic profile and metabolic function is essential for a better understanding of the nature of the pollution and restoration of the disturbed soils. The present study aimed to assess the long-term effect of oil on the ecological state of the soil, evaluate quantitative and qualitative differences in metabolite composition between soil contaminated with oil and non-contaminated soil, and reveal biologically active metabolites that are related to oil contamination and can be used for contamination assessment. A long-term field experiment was conducted to examine the effects of various oil concentrations on the biochemical properties and metabolic profile of the soil (Polyak et al., 2024).

One of the main environmental problems in the fuel and energy complex is the breakdown of oil pipelines, their wear and tear, as well as accidents caused by the transportation of crude oil and petroleum products by various means of transport. In recent years, the increase in the export of petroleum products through oil pipelines has led to environmental stress. As a result, the total volume of oil-contaminated land per 1–2 hectares reaches from 3,000 to 10,000 m^2, and the degree of soil contamination varies between 100–400 g/kg. Several factors affect the occurrence of waste: the drilling technology used to conduct drilling operations, the depth of the well, the water system used and the removal of water, natural and climatic factors, etc. During the construction of a 4500–5200 m well, 6-8 thousand cubic meters of drilling waste are generated (Ismailov, 2007).

The environmental consequences of crude oil pollution on soil properties are enormous. Oil pollution is of a great concern the world over. Even at the micro-level, contamination of the environment by crude oil is a global problem in that it leads to loss of vegetation, food insecurity and biodiversity. Based on the detrimental effects of crude oil pollution on soil and plants and its negative effects on food security as well as the environment, this study evaluates the effects of various levels of crude oil pollution grown with different plant species on soil physic-chemical properties (Ijah et al., 2018).

In recent years, projects implemented in the fields of improving the ecological situation in the country, including the efficient use of natural resources, restoration of polluted areas, protection of water resources, expansion of specially protected natural areas, forests and greenery, etc. have played their role in the restoration of ecological components. The soil cover, together with its microworld, is a very complex system that performs universal biological, absorbing, decomposing and neutralizing functions of various pollutants. The composition of the soil block consists of uncontrollable parameters (granulometric composition) and parameters that are practically difficult to control (organic and chemical composition), which allows determining the level of soil fertility and increasing fertility (Mammadov & Hakimova, 2003).

The application of low-emission technologies, restoration of oil-polluted areas, restoration of the ecological condition of water basins, and implementation of greening works have resulted in the improvement of the ecological situation, especially on the Absheron Peninsula, in the cities of Baku and Sumgait. Recently, one of the most demanded strategic products in all countries of the world is oil.

Depending on the degree of contamination, soils are classified as weakly, moderately and heavily contaminated. Oilfield areas are considered to be completely contaminated. In these areas, oil products are absorbed into the soil up to 100 cm along the profile, and the amount of oil varies between 7.8–9% (Mammadov & Khalilov, 2005).

It should be noted that oil loss during extraction, processing and transportation from the soil accounts for 5% of the total production. Comparative studies show that pollution with oil and its products has the greatest impact on the soil ecosystem. Thus, oil pollution has a very strong impact on the biodiversity and biological balance of the soil ecosystem, causing irreversible changes (Banks & Schultz, 2005; Dawson et al., 2007).

Methods

The research was conducted using generally accepted scientific methods. The study focused on the investigation of physicochemical, agro-physical, and biological properties of reclaimed soils. The main parameters analyzed included soil pH, salinity, salt migration, residual hydrocarbon content and its decomposition, as well as the number of microorganisms, which are important indicators of soil productivity. The following chemical analyses were performed on the collected soil samples: hygroscopic moisture content; granulometric and micro-aggregate composition (according to N.A. Kachinsky); absolute water density (D.V. Ivanov); carbonation; humus content (according to Tyurin); and pH measured in water suspension. The degree of contamination of oil-polluted soils was determined under laboratory conditions using the decantation method with benzene. The conducted chemical analyses provided a basis for assessing the current condition of the soils and ensured the scientific validity of the research.

Results and Discussion

The State Oil Company of Azerbaijan is currently implementing pilot projects aimed at the remediation of oil-contaminated lands. It is recommended to carry out greening and restoration measures in the area of an old oil field affected by oil waste contamination. The study area is a flat terrain with smooth relief, located inland from the sea and heavily polluted by oil. The soils are characterized by a light granulometric composition, low nutrient content, and salinity, and are located in the vicinity of oil fields. It should be noted that oil wells in the area were previously drilled using traditional methods. The depth of soil contamination ranges from 10–15 cm, and in some locations reaches 70–120 cm. Spilled oil remains in the soil for many years without complete degradation. The study area is the Muradkhanli Oil and Gas Field located in the Imishli region, which is affected by pollution resulting from oil production, processing, and transportation activities (Figure 1).

Figure 1
Oil-contaminated area

Soil samples were collected from the study area, and their coordinates were recorded for chemical analysis. To determine the concentrations of hydrocarbons and heavy metals, the samples were transferred to the soil analysis laboratory of "AzLab" LLC under the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan. The sampling coordinates were: No. 3 400 4 3.072 and No. 4 47 51 2189. The samples were analyzed using an ICP-MS 7700 inductively coupled plasma mass spectrometer. The results, including the hydrocarbon content, are presented in Table 1.

Table 1
Amount of hydrocarbons (%)

Petroleum hydrocarbons (%)	N3	N4
	9,2	5.3

The soil samples collected from the experimental area were found to be alkaline based on the soil solution analysis. The average pH ranged between 7.84 and 8.0. The concentrations of trace elements are presented in Table 3. According to Clark's standards, the levels of heavy metals in these soils are within permissible limits.

Previous studies have shown that microelements are predominant in some oil-contaminated soils. Among heavy metals, the most toxic elements for humans and animals include Hg, Pb, Cd, Zn, Cr, Ni, and Cu.

Soil contamination with heavy metals may originate from various sources, leading to the accumulation of toxic substances in the soil. Studies indicate that the concentrations of microelements vary among different soil types, resulting in a wide range of fluctuations. Therefore, biological responses to microelements also differ. Heavy metals, as major environmental pollutants, play a significant role in soil contamination processes.

Figure 2
Determination of toxic substances in soil and plant samples

The sampling was not conducted by "AzeLab". The samples were delivered to the laboratory by a representative of the customer. All analyses were performed at the "AzeLab" laboratory. These results apply only to the specified samples. Unsigned results are not valid. The laboratory reports may not be reproduced, distributed in incomplete form, or used for commercial or advertising purposes.

Table 2
Soil sample analysis results

No.	Indicators	Unit of measure	Sample name and quantity of components			
			N-1	N-2	N-3	N-4
1	Zn	mg/kg	326.6	47.4	232.7	58.3
2	Co	mg/kg	13.2	10.8	<LOD	8.4
3	Ni	mg/kg	15.7	30.2	<LOD	23.2
4	Cr	mg/kg	63.7	29.9	47.6	19.0
5	Mo	mg/kg	6.9	<LOD	19.3	2.6
6	Cd	mg/kg	0.75	<LOD	<LOD	2.9
7	Cu	mg/kg	85.4	98.1	85.9	47.2
8	Fe	mg/kg	140 800	36 400	110 600	25 880

9	Mn	mg/kg	953	749	810	836
10	Petroleum hydrocarbons	mg/kg	3 280	445	9 600	53

Table 3
Plant sample analysis results

No.	Indicators	Unit of measure	Sample name and quantity of components
			Plant
1	Na^+	mg/kg	24.5
2	K^+	mg/kg	2.72
3	Ca^{2+}	mg/kg	5.04
4	Mg^{2+}	mg/kg	18.5
6	Mo	mg/kg	0.013
7	B	mg/kg	0.79
8	Cu	mg/kg	0.002
9	Fe	mg/kg	0.23
10	Mn	mg/kg	0.09
11	Zn	mg/kg	0.02

Table 4
Amount of hydrocarbons in contaminated soil

No.	Indicators	Unit of measure	Sample name and quantity of components	
			N3	N4
1	Na^+	mg/kg	232.7	58.3
2	K^+	mg/kg	<LOD	8.4
3	Ca^{2+}	mg/kg	<LOD	23.2
4	Mg^{2+}	mg/kg	47.6	19.0
6	Mo	mg/kg	19.3	2.6
7	B	mg/kg	<LOD	2.9
8	Cu	mg/kg	85.9	47.2
9	Fe	mg/kg	110 600	25 880
10	Mn	mg/kg	810	836
11	Zn	mg/kg	9 600	53

Conclusion

The results of this study show that soils in the Muradkhanli oil and gas field are significantly affected by petroleum contamination. The hydrocarbon content (5.3–9.2%) indicates a high level of pollution, while the slightly alkaline pH (7.84–8.0) reflects changes in soil properties under contamination conditions. Although elevated levels of Zn, Cu, and Fe were detected, most heavy metals remained within permissible limits, suggesting that hydrocarbon pollution is the main environmental concern. However, the presence of these elements may pose potential ecological risks in the long term. The findings also indicate the limited natural self-remediation capacity of the soils, highlighting the need for effective remediation strategies such as bioremediation and phytoremediation. Further studies with expanded sampling and long-term monitoring are recommended.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 40–44
DOI: https://doi.org/10.36719/2707-1146/65/40-44

The Effect of Organic Fertilizers on Nutrient Absorption in Different Agrocenoses of Brown Meadow Soils of Shirvan

Aygun Aliyeva

Abstract. *The cultivation of agricultural crops involves intensive interactions between humans and nature, often resulting in soil degradation and reduced fertility. This study examines the impact of organic fertilizers on the fertility and agrochemical properties of brown meadow soils in the Shirvan Plain of Azerbaijan. The main objective was to evaluate the effectiveness of organic fertilizers, particularly manure, in improving soil characteristics and nutrient availability under irrigated vegetable crops. Field experiments and laboratory analyses were conducted to assess soil properties at different depths, including humus content, nitrogen, phosphorus, potassium, density, and porosity. The results demonstrated that the application of organic fertilizers significantly increased humus content and essential nutrients, improved soil structure, and enhanced microbial activity. The formation of water-resistant aggregates was also observed, contributing to greater soil stability. Overall, the findings indicate that the consistent use of organic fertilizers supports the restoration of soil fertility and promotes sustainable agricultural development.*

Keywords: *soil fertility, organic fertilizers, humus, nutrients, soil properties*

Introduction

In 2016, in order to develop the non-oil sector in the national economy of the country, a "Strategic Roadmap" on the production and processing of agricultural products was developed in the Republic of Azerbaijan. Based on the principles of sustainable development, this document aims to strengthen food security, increase the production potential of agricultural products, and improve the quality of education and scientific support during 2016–2020.

The Shirvan Plain is located in the northern part of the Kura-Araz lowland and stretches along the left bank of the Kura River, from the Bozdag mountain range to the desert zone. The irrigation and reclamation system of this plain is mainly associated with the Mingachevir reservoir, which regulates the water regime of the Kura River. The Shirvan zone is divided into mountainous and lowland areas.

The total area of the region is 1,134 thousand hectares, of which 652 thousand hectares are used in agricultural production. The sown area is 247 thousand hectares, including 175 thousand hectares under irrigation. However, up to 70% of the lands in the Shirvan Plain are currently not used in agriculture due to insufficient water resources, repeated soil salinization, and other limiting factors.

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Received: 2 January 2026; Accepted: 9 March 2026; Published online: 25 April 2026

According to long-term observations, the first autumn frosts occur in late November to early December, while the last spring frosts are observed between April 4 and 7. The duration of frost-free days is 240–260 days. During the study years, meteorological indicators were close to long-term averages. Climatic conditions play a crucial role in the formation and differentiation of landscapes and directly influence soil properties and agricultural productivity (Paustian et al., 2016).

In this context, the study of soil properties and the role of organic fertilizers in irrigated agricultural systems becomes particularly important. The impact of organic fertilizers on the structural composition and physical properties of soils under irrigated vegetable crops in brown meadow soils of the Ujar region has not been sufficiently studied. Soil structure, particularly the formation of water-resistant aggregates, significantly affects soil density and porosity (Deru et al., 2023).

Atmospheric precipitation is one of the key factors influencing plant development (Lehmann & Kleber, 2015). Due to insufficient rainfall in the Shirvan region, agricultural lands are artificially irrigated, which contributes to the accumulation of moisture in the soil. During hot periods, this moisture partially compensates for losses caused by intensive evaporation. Soil processes and plant development are closely related to air humidity (Lal, 2015).

K.A.Alekperov and A.G.Zeynalov determined that in brown soils the humus content in deep layers is low and amounts to 1.5−2.5%, and the carbonate content in deep layers is 15−20%. Brown meadow soils develop in the central part of the plain, while carbonate soils develop in the depressions. According to R.Kh.Mamedov, the humus content in these soils is 2−3%, corresponding to 300-400 tons per hectare. In brown meadow soils, humus content ranges from 2–3%, corresponding to 300–400 tons per hectar. Humus plays a key role in soil fertility as it contains essential nutrients, improves physical and chemical properties, and enhances biological activity (Lal, 2016; Jafarov, 2023).

The formation of humus occurs in two stages: decomposition of complex organic compounds and synthesis of humus substances from intermediate products (Deru et al., 2023). Organic fertilizers, including manure, peat, and green manure crops, contribute to increasing humus content, improving soil structure, and enhancing microbial activity (Allam et al., 2022; Sedlář et al., 2023).

Therefore, the main objective of this study was to determine the optimal dose of organic fertilizers applied to vegetable crops in brown meadow soils of the Shirvan Plain and to assess their impact on soil fertility, nutrient uptake by plants, and nutrient utilization efficiency.

Materials and Methods

The study was conducted on brown meadow soils in the Shirvan Plain, specifically in the Ujar region, under irrigated conditions. The research focused on vegetable crops cultivated in this area.

Soil samples were collected from different depths of the soil profile, including 0–20, 20–40, 40–60, and 60–80 cm layers, to evaluate the mechanical and physical properties of the soil.

The study included the investigation of soil-climatic conditions of the research area, as well as the analysis of agrochemical, agrophysical, and hydrophysical properties of the soil. Particular attention was given to soil structure, density, porosity, and the formation of water-resistant aggregates.

Organic fertilizers were applied to assess their effect on soil fertility, nutrient dynamics, and plant nutrient uptake. The influence of these fertilizers on soil structural parameters and nutrient utilization efficiency was evaluated based on observed changes in soil properties and plant development (Tong et al., 2022).

Results and Discussion

The main property of soil is its fertility. Fertility is the soil's ability to provide air, water, and nutrients for the normal survival and fruiting of plants.

Table 1
Mechanical and physical composition of soils in the experimental plot

Depth, cm	Number of water-resistant units, %							Physical properties	
	>7	7–5	5–3	3–1	1–0,25	>0,25	<0,25	Density, q/cm^3	Porosity, %
0–20	7,0	9,4	10,4	15,1	20,8	63,5	36,5	1,00	57,00
20–40	7,0	10,0	9,9	13,0	22,0	48,0	33,0	1,13	51,25
40–60	6,8	8,8	8,0	10,0	19,8	44,0	35,0	1,23	50,05
60–80	6,1	7,0	6,5	–	–	36,0	30,6	1,39	45,50
				–	–	31,0	24,5	1,64	44,55

Table 1 shows that the number of relatively large aggregates with particles from 7 mm is 70%, with particles within 7–5 mm – 9.4%, 5–3 mm – 10.4% and 3–1 mm – 15.1%.

It is known that the role of organic fertilizers in the formation of aggregates resistant to water is great. Silt particles and organic compounds combine to increase the number of aggregates resistant to water. This process occurs most intensively in a humid environment. At the same time, during this period, with an increase in the activity of microbiological processes, the relationship between soil aggregates increases. Therefore, such soils are characterized by a rich content of aggregates with higher resistance to water (Fan et al., 2023).

It is known that the development of vegetable crops and their yields depend on the amount of nutrients in the soil. Knowing the potential fertility of the soil, it is possible to determine the variety and rate of organic fertilizers used for tomatoes. Properly selected fertilizers promote the transfer of soil nutrients into a form that is easily assimilated by plants.

Organic fertilizers, along with enriching the soil with essential nutrients for plants, also improve its overall agrochemical properties. The agrochemical features of the brown meadow soils of the Ujar region in the study area are given in Table 2.

Table 2
Agrochemical characteristics of brown meadow soils of the Ujar district

Depth, cm	Ph (water)	Humus, %	Nitrogen		Phosphorus		Potassium	
			General, %	Assimilated $N\text{-}NH_4$ mg/kg	General, %	Mobile P_2O_5 mg/kg	General %	Exchange K_2O mg/kg
0-20	7,2	2,73	0,25	33,4	0,15	16,2	2,62	241,0
20-40	7,5	2,00	0,13	28,5	0,12	14,4	2,36	240,0
40-60	7,7	1,66	0,11	21,7	0,07	11,8	1,23	125,2
60-80	7,8	0,55	0,05	13,2	–	8,7	1,15	100,7

Organic fertilizers, including manure, are of great importance for increasing soil fertility, improving its physicochemical properties, as well as increasing plant productivity and quality (Acar et al., 2025).

To increase soil fertility, siderate plants are considered one of the best remedies. Sideral crops are considered the best way to increase soil fertility. Siderates are plants whose green mass enriches the soil with organic substances and nitrogen. Siderates have long been used in agricultural practice (Lehmann, 2020).

Conclusion

The application of organic fertilizers in brown meadow soils of the Shirvan Plain significantly influenced the availability of nutrients for plant uptake. In the treatment with 30 tons of manure, the content of ammonium nitrogen in the arable and sub-arable layers ranged from 16.21 to 13.20 mg/kg, nitrate nitrogen from 4.95 to 3.97 mg/kg, mobile phosphorus from 15.33 to 13.00 mg/kg, and exchangeable potassium from 225.00 to 211.00 mg/kg.

The results indicate that organic fertilizers not only increase the content of essential nutrients in the soil but also improve its overall agrochemical properties. This confirms the effectiveness of organic fertilizers in enhancing soil fertility and supporting sustainable agricultural production in the region.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 45–49
DOI: https://doi.org/10.36719/2707-1146/65/45-49

Species Composition and Bioecological Characteristics of Major Entomophages Against Ornamental Plant Pests in Absheron

Elnura Safarova[1*], Irada Mustafayeva[2]

Abstract. *Extended research on both native and introduced ornamental plants in parks, boulevards, sports complexes, and residential zones of the Absheron Peninsula has documented 72 species of entomophages that play an important role in the biological control of pest populations. These species are classified within 4 orders and 12 families, consisting of 46 parasitoid species and 26 predatory species. Among the recorded taxa, 14 species belong to the family Braconidae, 8 to Ichneumonidae, 18 to Chalcidoidea, 1 to Bethylidae, 1 to Scoliidae, 4 to Tachinidae, 5 to Carabidae, 1 to Histeridae, 2 to Staphylinidae, 4 to Dermestidae, 10 to Coccinellidae, and 3 to Chrysopidae. In addition, 15 of these species have been identified as new records for the fauna of Azerbaijan, while 25 species have been documented for the first time in the Absheron region. Altogether, 14 parasitoid and predatory species were evaluated as economically important, and 9 of them were recognized as potentially suitable for application in biological control and integrated pest management programs.*

Keywords: *Absheron, pest, entomophage, bioecological, ornamental plants, species*

Introduction

In recent years, research has focused on integrated and biological methods for controlling plant pests. This shift is driven by the ecological risks of chemical pesticides and their negative impacts on human health, highlighting the need for safer alternative approaches. In this context, developing scientifically grounded biological control strategies for insect pests of both native and introduced ornamental plants is especially important. Observations in the Absheron Peninsula show that parasitoid and predatory entomophages play a key role in controlling pests, making it important to study their composition and bioecological traits for integrated pest management. Research in the Absheron region has thus focused on documenting entomophage diversity, understanding their pest-control mechanisms, and assessing their potential in biological control programs (Safarova, 2013, pp. 75–108; Valiyeva & Hasanova, 2022).

Methods

The study was conducted on the Absheron Peninsula during the vegetation season from April to October. Field surveys were carried out to identify parasitoid and predatory entomophages associated with major ornamental plant pests.

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Received: 4 January 2026; Accepted: 28 March 2026; Published online: 25 April 2026

Insects were collected using standard entomological methods such as direct observation, hand sampling, and sweep netting. Host infestation levels were assessed by recording the presence and activity of entomophages on infested plants, and infestation degrees were classified on a scale from I to III. Species identification was performed using morphological keys, focusing on Hymenoptera (Braconidae, Ichneumonidae, Chalcidoidea, Aphelinidae, Encyrtidae), Diptera (Tachinidae, Sarcophagidae), Coleoptera (Carabidae, Staphylinidae, Dermestidae, Cleridae, Coccinellidae), and Neuroptera (Chrysopidae). The seasonal activity periods of each species were determined by repeated observations throughout the growing season (Agasyeva et al., 2023).

Results

Infection periods and degrees of major ornamental plant pests by entomophages in the Absheron Peninsula.

Parasitoid Hymenoptera (*Braconidae, Ichneumonidae, Chalcidoidea*, etc.)

Bracon hebetor, Br. Variegator, Br. Intercessor → active IV–X; infestation degree I–III. *Agathis malvacearum, Microdus dimidiator, Macrocentrus linearis* → active IV–IX; degree III. *Ascogaster 46ariegate46ate, Apanteles solitarius, A. fulvipes, A. spurius* → active IV–X; degree I–III. *Meteorus 46ariegat, M. versicolor, Theronia atalantae, Pimpla turionella, P. examinator, P. instigator* → active V–X; degree II–III. *Itoplectis europeator, I. alternans, Agrypon stenostiqma, Scambus calobata* → active IV–IX; degree I–III. *Eulophus chrysomella, Brachymeria intermedia, Tetrastichus evonymellae, Monodontomerus obsoletus, Elasmus albipennis* → active IV–VIII; degree I–III. *Trichogramma cacoeciae, Tr. Evanescens* → active V–VIII; degree I.

Parasitoid Hymenoptera (*Aphelinidae, Encyrtidae*, etc.)

Aphytis mutilaspidus, Aph. Proclia, Archenomus caucasicus, Ar. Bicolor, Cocophagus lycimnia, Anagyrus psedococci → active IV–X; degree I–III. *Pseydophycus malinus, Encyrtus lacaniorum, Encarsia perniciosis, E. partenopea* → active VI–VIII; degree I–III.

Diptera Parasitoids (*Tachinidae, Sarcophagidae*, etc.)

Perisierola qalicolla, Scolia quadripunctata, Eurythaea scutellaris, Tachina praeceps, Phorosera silvestris, Parasarcophaga portchinskiy → active IV–X; degree I–III. Predatory Coleoptera (Carabidae, Staphylinidae, Dermestidae, Cleridae, Coccinellidae). *Carabus granulatus, C. bessiz, C. scabris, Calosoma sycophanta, C. inguisitor* → active V–X; degree I–III. *Cylister lineare, Placusa depressa, Nudobius lentus* → active IV–VIII; degree I–III. *Dermestes 46ariegate, D. bicolor, D. ater, D. undulatus* → active V–IX; degree I–III. *Thanasimus formicarius* → active IV–VII; degree I. *Chilocorus bipustulatus, Ch. Renipustulatus, Adalia bipunctata, A. decimpunctata, Coccinella septempunctata, Semiadalia undecimnotata, Holysia sedecimpunctata, Adonia 46ariegate, Scymnus frontalis, Radolia cardinalis* → active IV–X; degree I–III. Predatory Neuroptera (Chrysopidae). *Chrysopa carnea, Ch. Septempunctata, Ch. Perla* → active IV–IX; degree I–II. Research carried out in the Absheron Peninsula identified 72 species of entomophages. Their activity periods predominantly spanned from April to October, with host infestation levels ranging from I to III. Both parasitoid and predatory species were shown to contribute significantly to the natural control of pest populations (Safarova, 2013, pp. 75–108).

Discussion

Entomophages—both parasitoid and predatory insects are key to the biological control of plant pests (Landis et al., 2000; Symondson et al., 2002), and collecting data on their diversity, life cycles, host interactions, and distribution is essential for developing scientifically grounded integrated pest management strategies (Apazhev et al., 2020; Almeida et al., 2022; Bale et al., 2019; Letourneau et al., 2021). Long-term research carried out in the Absheron Peninsula has recorded numerous entomophage species and analyzed their bioecological traits. Examining these traits helps understand the natural pest control role of entomophages, and this study presents the bioecological characteristics of key species affecting ornamental plants in the Absheron region (EFSA Panel on Plant Health, 2021).

Bioecological characteristics of the parasite Ascogaster in Absheron

Among the main parasites of ornamental plant pests in the Absheron region are *Archips rosana* (rose leafroller), *Spilonota ocellana* (bud moth), and *Recurvaria nanella* (leaf moth). The ascogaster parasite plays an important role in the biological control of *Archips rosana*. Field observations in household gardens of Absheron (Mashtaga, Novkhani, and Nardaran) showed that ascogaster overwinters within the body of first-instar host larvae. In spring (late April to early May), the overwintered parasite larva feeds internally on the host's tissues. After completing three larval stages, pupation takes place either on the remains of the last host larva or occasionally near the host pupa (Miller & Davidson, 2005). The pupae are white with a noticeable transverse band, and pupal development lasts 15–16 days at 20–22 °C. The full development from egg to adult requires 35–40 days, with the species producing two generations per year. Adults live 15–25 days under natural conditions, feeding on nectar before reproduction. Adults of the second generation lay eggs on rose leafroller larvae during August–September (Bennett et al., 2019**)**. The larval stage of the parasite coincides with the appearance of host larvae. Infected host larvae reach the second and third instars but, along with the parasite, enter diapause beneath tree bark for overwintering. In spring, parasitized larvae do not complete development, and the parasite pupates inside the host. Adults emerge in May, flying until September. Ascogaster lowers leafroller populations by 20–25%, showing promise for integrated pest management, particularly if mass-rearing in the lab is developed (Mirzoeva, 2001, pp. 41–52).

Bioecological characteristics of *Apanteles solitarius*

Apanteles solitarius is a key parasitoid involved in the biological control of ornamental plant pests, especially Lepidoptera larvae such as the bud moth (Spilonota ocellana), rose leafroller (Archips rosana), and hawthorn moth (Hyponomeuta spp.). Field observations in the botanical gardens and dendraria of Absheron have indicated that females can lay up to 2000 eggs over their lifetime, depositing them individually inside host larvae. The development of the parasitoid is closely synchronized with host growth, occurring within the fourth and fifth larval instars. Mature larvae leave the host, form yellowish cocoons, and pupate internally or externally, overwintering as pupae or late-instar larvae (Nadein & Perkovsky, 2018, pp. 97–106). The species has three generations per year, with adults appearing from late April onward. Nectar plants like alfalfa, milkweed, and dill boost reproduction and parasitism, while chemical controls reduce activity. The first generation of A. solitarius parasitizes 60–80% of hawthorn moth larvae, while later generations affect 8–10% of bud moths and 6–8% of rose leafrollers. These characteristics make the species a valuable candidate for integrated pest management programs. It is widely distributed across the Palearctic region, the Caucasus, and several regions of Azerbaijan, including Quba, Khachmaz, Shusha, Ordubad, and Nakhchivan.

Bioecological characteristics of *Scambus calobota*

Scambus calobota is common across the Absheron Peninsula, especially on flowering plants like alfalfa, and parasitizes larvae of silk moth, golden moth, "beautiful moth," and hawthorn moth. Females generally lay a single egg on second or third instar host larvae. Larval development within the host lasts approximately 5–6 days, followed by pupation for 10–12 days. The entire life cycle is completed within 20–25 days, with adults overwintering beneath tree bark (Mammadov, 2004). Activity occurs from early May to late July. Field observations indicate significant parasitism rates: silk moth larvae 32–37%, golden moth larvae 20–23%, and "beautiful moth" larvae 26–30%. These results underscore the species' important role in controlling pest populations in ornamental plantings. In the Absheron region, *Scambus calobota* helps control pests in rose gardens and orchards, especially in household plots where chemical control is not used. It produces two generations per year: the first attacks young silk moth larvae, and the second targets golden moth and “beautiful moth” larvae. Under laboratory conditions at 22–24 °C, adults survive 12–16 days when provided with a sugar solution, but only 3–4 days without food. This parasitoid is considered highly valuable for biological control, with significant practical potential for use in integrated pest management programs (Zhang, 2025).

Bioecological Characteristics of *Aphytis proclia*

Aphytis proclia is an oligophagous ectoparasitoid, primarily associated with the California red scale (Aonidiella aurantii), although it can also parasitize other hosts. Females lay eggs externally by piercing the host’s scale and attaching eggs to its surface; the larvae feed on the host’s internal tissues and complete development beneath the scale. Pupation and adult emergence occur within this protective covering. The species produces up to five generations per season, with flight activity observed from mid-May to September. Its population dynamics are strongly affected by host availability, as early generations often coincide with low numbers of female scales, leading to reduced parasitism rates. Supplemental feeding on nectar-producing plants, such as Phacelia, significantly improves adult longevity (exceeding one month) and fecundity (40–75 eggs), thereby enhancing parasitism levels (De Curtis et al., 2019**)**. Field observations have demonstrated that in orchards with flowering Phacelia, infestation of California red scale by Aphytis increased from 1% prior to flowering to over 70% afterward, resulting in a 2.5-fold decrease in pest density by the end of the growing season. In the Absheron Peninsula, parasitism rates of California red scale reach 15–20% in May–June and 30–35% in September, underscoring the species’ practical value for biological control (Safarova, 2013, pp. 75–108).

Conclusion

In conclusion, research on the Absheron Peninsula shows that 72 entomophage species provide effective natural control of ornamental plant pests. Active mainly from April to October, they include parasitoid Hymenoptera, Diptera, predatory beetles, and neuropterans, all contributing at infestation levels between I and III. Their overlapping activity periods ensure continuous regulation, keeping pest populations below economic thresholds. This ecological balance reduces dependence on chemical treatments and offers a strong foundation for integrated pest management in the region. In conclusion, recent research highlights the growing importance of integrated and biological methods for pest control as safer alternatives to chemical pesticides. Studies in the Absheron Peninsula demonstrate that parasitoid and predatory entomophages are central to regulating ornamental plant pests, underscoring the need to document their diversity and bioecological traits. By understanding their mechanisms and seasonal activity, these natural enemies can be effectively incorporated into biological control programs, providing a sustainable foundation for integrated pest management while reducing ecological and health risks. Surveys in the Absheron Peninsula revealed 72 entomophage species across 4 orders and 12 families, reflecting high biodiversity in ornamental plant ecosystems. Fifteen species were new for Azerbaijan’s fauna and 25 were first records for Absheron. Fourteen parasitoid and predatory species were considered economically important, with nine identified as promising candidates for biological control and integrated pest management, offering strong potential for sustainable pest regulation.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 50–55
DOI: https://doi.org/10.36719/2707-1146/65/50-55

Study of the Parameters of Obtaining Low Lactose Whey Suitable For Baby Food

Tarana Aghayeva[1*], Fatima Aghayeva[2]

Abstract. *Since childhood is characterized by rapid metabolic processes, the development of organs and body systems, and the formation of functional activity, nutrition is especially important for a child. It is known that breast milk is the most rational and important method of feeding a child, as it contains all the essential nutrients a child needs during this period. Breast milk lays the foundation for future health, preventing diabetes, coronary heart disease, obesity, and other diseases. Breastfeeding also has a profound emotional impact, bringing mother and child closer together during feeding, and this desire for each other lasts a lifetime. Breastfeeding is not always possible. Many mothers develop hypogalactia, and milk production ceases completely. Illnesses of both mother and child, premature birth, and other factors can lead to the cessation of breastfeeding. Children deprived of breast milk are transferred to artificial feeding using specially adapted formulas that are as close as possible to breast milk. Thanks to new information about the individual components of breast milk, work is constantly underway to create and improve adapted formulas. Due to its amino acid content, the use of milk protein in infant formula is very convenient. Whey protein is more easily digested than powdered milk. However, the lactose it contains can sometimes negatively impact digestion, making it difficult for infants to digest. For this reason, it is possible to hydrolyze the lactose contained in the protein to the required concentration. This article examines the parameters affecting lactose hydrolysis and tests optimal options. The temperature, enzyme concentration, and hydrolysis time required for adequate lactose hydrolysis are determined.*

Keywords: *breast milk, baby food, artificial formula, whey, lactose hydrolysis*

Introduction

Another term used to describe fermented milk products is "probiotic products." This definition refers only to fermented milk products containing probiotic microorganisms (Wijesekara et al., 2025). Over the years, significant work has been done to improve the composition of these products, select ideal starter cultures, and study their effectiveness in both healthy and sick children (Jena & Choudhury, 2025). One of the major achievements is the development of high-quality dry fermented milk products, which has made it possible to provide children living in remote areas with modern, high-quality fermented milk products. These products are manufactured under strict quality and safety controls in large factories equipped with specialized equipment (Baranov & Sher, 2023).

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Received: 3 January 2026; Accepted: 17 March 2026; Published online: 25 April 2026

It is well known that breast milk is the most rational and important way to feed a child, as it contains all the essential nutrients a child needs during this period. Breastfeeding lays the foundation for future health, preventing diabetes, coronary heart disease, obesity, and other diseases. Breastfeeding also has a profound emotional impact; feeding brings mother and child closer together, and this bond lasts a lifetime. These children become wonderful parents who love and care for their children.

Breastfeeding is not always possible. Many mothers develop hypogalactia, and milk production ceases completely. Illnesses of both mother and child, premature birth, and other factors can lead to the cessation of breastfeeding. Children deprived of breast milk are transferred to formula feeding using adapted formulas, which are as close as possible to breast milk. In recent years, adapted formulas have been supplemented with pre- and probiotics, nucleotides, lutein, and long-chain fatty acids, and their mineral and vitamin composition has been improved (Ladodo, 2019). Despite advances in the composition of adapted formulas, some children experience allergic reactions and digestive problems when using them, and these children are more likely to suffer from respiratory and intestinal diseases than breastfed children. The renowned Russian pediatrician Georgy Nestorovich Speransky decided to use fermented milk products for children and, in 1922, opened a milk kitchen at the Institute of Mother and Child, which he headed, and began producing diluted kefir (Gao Yu et al., 2016). He described his experience organizing a milk kitchen and producing products there, including kefir-based formulas, in his book "The Milk Kitchen" (Baranov & Sher, 2023).

In recent years, pre- and probiotics, nucleotides, lutein, and long-chain fatty acids have been added to adapted milk formulas, and the mineral and vitamin composition has been improved. Research by various scientists shows that using whey instead of powdered milk during formula feeding yields better results (Tang et al., 2025).

Methods

Whey is a valuable secondary raw material. The feasibility of its use has been discussed by many authors (Raimbekov et al., 2018), and the following key aspects of its application should be emphasized:

- nutritional value, allowing whey to be used in the preparation of functional foods;
- reduction of dairy industry emissions and a reduction in the overall negative impact on the environment;
- availability of whey as a raw material, taking into account production volume data;
- reduction in the cost of finished products due to partial or complete replacement of dairy raw materials without loss of finished product quality.

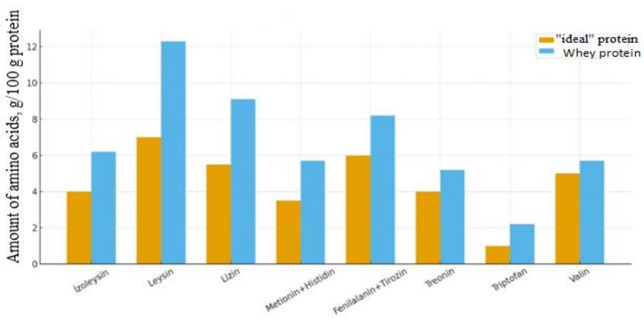

Figure 1

Composition of essential amino acids in whey protein and “ideal” protein Whey proteins are known to contain all essential amino acids, and their amino acid composition is close to that of an "ideal" protein (Table 1 and Figure 1) (Gorissen, 2018)

Table 1
Composition of essential amino acids in whey protein and “ideal” protein

Essential amino acids	Amount of amino acids, g/100 g protein	
	The "Ideal" Protein	Whey protein
Isoleucine	4,0	6,2
Leucine	7,0	12,3
Lysine	5,5	9,1
Methionine, histidine	3,5	5,7
Phenylalanine, tyrosine	6,0	8,2
Threonine	4,0	5,2
Tryptophan	1,0	2,2
Valine	5,0	5,7

Using enzyme preparations for whey lactose hydrolysis is less expensive in terms of equipment and product quality, and therefore offers significant opportunities for the dairy industry. To study the process of whey lactose hydrolysis, the enzyme preparation β-galactosidase Nola Fit®, obtained by submerged fermentation of a selected Bacillus licheniformis strain, was selected (Bella et al., 2024). The following parameters were selected for the whey hydrolysis study using β-galactosidase:

- hydrolysis temperature;
- pH of the medium;
- hydrolysis time;
- enzyme concentration.

Process efficiency was monitored by measuring the residual lactose content in the hydrolysate. Hydrolysis temperature is an important parameter for the enzymatic reaction (Lukushkina et al., 2015).

The effect of temperature on lactose content in the system was studied to determine the optimal hydrolysis temperature. Hydrolysis was carried out for 2 hours at pH 6.0 with enzyme concentrations of 0.01%, 0.03%, 0.05%, and 0.07%. The data are presented in Figure 2.

The figure shows that increasing the enzyme concentration reduces the residual lactose content. At an enzyme concentration of 0.03%, the lactose concentration in the system drops sharply, and further increases in enzyme concentration have virtually no effect on the process.

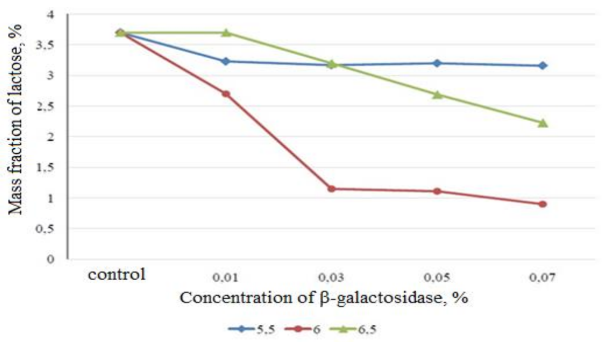

Figure 2
Dependence of residual lactose content on hydrolysis temperature and β-galactosidase concentration

At a temperature of 45 ± 1 °C, lactose hydrolysis proceeds more slowly, which can be explained by accelerated thermal denaturation of the enzyme, leading to a decrease in its activity. The optimal temperature for whey hydrolysis is 40 ± 1 °C. This temperature is characterized by the lowest residual lactose content. At enzyme concentrations of 0.03%, 0.05%, and 0.07%, the lactose content was 1.15%, 1.11%, and 0.9%, respectively.

To assess the effect of pH on lactose hydrolysis, the enzyme preparation was tested at concentrations of 0.01%, 0.03%, 0.05%, and 0.07%. The process temperature was 40 ± 1 °C, and the duration was 2 hours. Whey acidity was adjusted using sodium carbonate salts. The obtained data are presented in Figure 3.

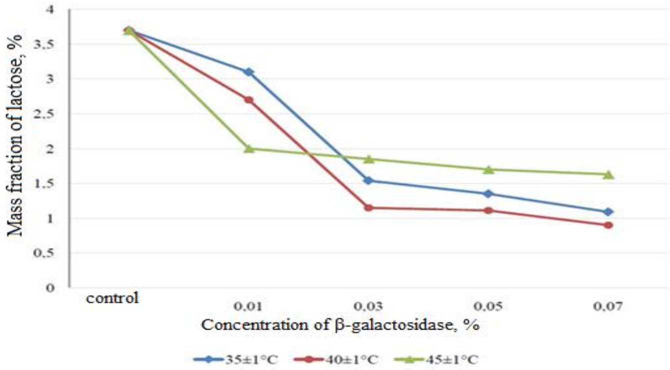

Figure 3
Dependence of lactose content on the acidity of the medium and the concentration of β-galactosidase

At pH 5.5, the amount of residual lactose in whey remains virtually unchanged, and increasing the enzyme concentration does not alter the hydrolysis process. At pH 6.5 and an enzyme concentration of 0.01%, lactose hydrolysis does not occur, and with an increase in concentration from 0.03% to 0.05%, it becomes less intense than at pH 6, indicating that these conditions are unsuitable for the production of hydrolyzed whey (Gao et al., 2016).

Results and Discussion

Lactose hydrolysis duration was determined at enzyme concentrations of 0.01%, 0.03%, 0.05%, and 0.07%, at a pH of 6 and a temperature of 40±1 °C. Hydrolysis was carried out for 2, 3, 4, and 24 hours. Process intensity was assessed by the decrease in lactose mass fraction. The data are presented in Table 2.

Table 2
Effect of hydrolysis duration and enzyme concentration on lactose content

Concentration of β-galactosidase, %	Mass fraction of lactose, %			
	2 hours	3 hours	4 hours	24 hours
control	3,70	3,70	3,70	3,70
0,01	2,70	2,50	2,50	0,60
0,03	1,15	1,00	0,61	0,60
0,05	1,11	0,61	0,60	0,45
0,07	0,90	0,45	0,45	0,10

Studies have shown that as the time of exposure of whey to β-galactosidase increases, lactose hydrolysis continues, and its content decreases to 0.1%. The most intense lactose hydrolysis occurs at an enzyme concentration of 0.05% and a processing time of 3 hours, as well as at an enzyme concentration of 0.03% and a processing time of 4 hours. Further increases in concentration at the indicated hydrolysis times have little effect on reducing residual lactose content. At all enzyme concentrations and a hydrolysis time of 24 hours, the lactose content is less than 0.6%. This process time ensures the maximum degree of hydrolysis under these conditions, but is not optimal (Granier et al., 2013).

Based on the obtained data, the determined parameters of whey hydrolysis using the enzyme preparation β-galactosidase Nola Fit® are presented in Table 3.

Table 3
Optimal parameters for lactose hydrolysis in whey

Parameters			
Concentration of β-galactosidase, %	pH	Temperature, °C	Duration, hours
0,05 ± 0,005	6,0 ± 0,1	40 ± 1	3

The lactose content of whey impairs its processing; its low sweetness, solubility, and microbial fermentation limit its use in the creation of functional foods. Using a lactose modification method based on selected parameters allows the production of whey with a low lactose content and improved properties (residual lactose content does not exceed 0.61%), suitable for use as a base for pectin-whey gels in the creation of functional foods (Schurman et al., 2010).

Conclusion

The results of these studies support the successful use of low-lactose whey in the preparation of infant formula. The nutrients obtained from using this whey will not only be easily absorbed by the baby's body but will also promote healthy growth.

1. Using whey from various dairy products in baby food is more effective than using dry milk powder.
2. The lactose content of whey is affected by its concentration, pH, and hydrolysis time.
3. Whey hydrolyzed to lactose can also be used in the preparation of other functional foods.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 56–60
DOI: https://doi.org/10.36719/2707-1146/65/56-60

Comprehensive Investigation of the Physicochemical Properties of the $CdSb_2S_4$ Compound
(Chemical and X-Ray Phase Analysis, Precipitation Kinetics)

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Abstract. *In this work, the physicochemical properties of the cadmium antimony sulfide compound $CdSb_2S_4$ in an aqueous environment were studied. To synthesize cadmium antimony sulfide, local raw materials were first used as the starting material. Antimony (III) sulfide was obtained from the Daridag antimony mine located in the Nakhchivan Autonomous Republic by filtration. Antimony (V) sulfide and cadmium sulfide were added to the obtained antimony (III) sulfide, and cadmium sulfide was synthesized. Cadmium antimony sulfide was X-ray diffraction (XRD) analysis of the obtained compound was performed. At the same time, the precipitation rate of the compound was calculated, the results of which are listed in the table. The effect of the amount of cadmium sulfide on the formation of cadmium antimony sulfide was studied and given in the table. The sample was chemically analyzed and its composition was determined. The application areas of cadmium antimony sulfide are defined, and brief information is provided (optoelectronics, thermoelectric materials, solar energy technologies, photocatalysis).*

Keywords: *cadmium sulfide, cadmium antimony sulfide, x-ray phase, precipitation, chemical analysis*

Introduction

A new thioantimonate(III) of the d10 transition metal $CdSb_2S_4$ was prepared by an environmentally friendly ionothermal method (Gang, 2021). The conditions for obtaining cadmium thiostibite from the interaction of cadmium acetate and antimony(III)chloride in an organic medium have been studied (Guliyev, 2017). A thin film of cadmium sulfide is deposited on a glass slide using a pyrolysis-deposition method at high temperature (400 °C) using an aqueous solution of cadmium chloride and thiourea. The structural, optical and electrical properties of the deposited CdS thin film are investigated (Abhijit, 2011). To determine their physicochemical properties, measurements were made using spectrophotometer, X-ray diffraction (XRD), step height measurement device, digital four-point probe resistance measurement and scanning electron microscopy (SEM) (Chen, 2022).

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Received: 11 January 2026; Accepted: 21 March 2026; Published online: 25 April 2026

In the 21st century, the combination of heavy metals and sulfide-based semiconductor materials has attracted great interest due to its scientific and practical importance (Valiyeva, 2025). These antimony-based compounds are distinguished by their high optical absorption, wide band gap, and various physicochemical properties, and have wide application possibilities in optoelectronics, solar energy devices, and sensor technologies (Fatemipayam, 2025).

Methods

We used Daridag antimony ore as the starting raw material for the preparation of cadmium thiostibite compound (Garayev, 2017, 2022). Antimony (III) sulfide and then antimony (V) sulfide are synthesized from Daridag antimony ore (Garayev, 2016; Aliyeva, 2024). Cadmium thiostibite ($CdSb_2S_4$) is obtained from the interaction of antimony (V) sulfide and cadmium sulfide. The amount of cadmium sulfide added to antimony (V) sulfide is taken in a ratio of 1.2–1.4:1. The sample size varies between 0.17–0.182 mm, the ratio of antimony (V) sulfide to cadmium sulfide in the ore is 1:1.3 (Aliyeva, 2021; Aliyeva, 2022). The process proceeds at a temperature of 423–473 K with a solid-liquid phase ratio of 1:5–7. The completion time of the process is about 20–30 minutes, and the yield of antimony (V) sulfide is about 94.50%. Antimony (V) sulfide obtained from Daridag antimony ore is dissolved in HCl, and at this time the compound is purified from impurities. At about 430K, hydrogen sulfide (H_2S) is evaporated from antimony (V) sulfide. At this time, the solution changes color from dark brown to yellowish orange. Precipitation occurs and the precipitation of sulfide stops. The obtained antimony (V) sulfide is washed until chlorine and sulfide ions are purified, and finally washed again in 55ml of ethylene glycol. We dry it in vacuum at 467K until a constant mass is obtained. The preparation of cadmium thiostibite is as follows:

$$CdS+Sb_2S_5 \rightarrow CdSb_2S_4+2S$$

In this reaction, the substances taken are mixed, boiled, and water is added occasionally, and the boiling is continued until the dissolution process is complete. Finally, the solution is allowed to crystallize.

Results

The resulting grayish-yellow crystals are filtered through a Buchner funnel. If we take the amount of cadmium ions less than the equivalent amount, we will get a compound consisting of a mixture of cadmium sulfide and antimony (V) sulfide. This compound we get is not completely separated from the solution. In order for the pH to take a certain value, we must take the amount of antimony (V) sulfide according to the reaction. In this case, the reaction proceeds according to the exchange mechanism. It can be seen from the table below that the theoretical and experimental masses of the sample are close to each other (Sb_2S_3=20–35 ml). It can be seen from Table 1 that the process proceeds according to the exchange reaction.

Table 1
Effect of the amount of cadmium sulfide on the formation of cadmium thiostibit [Sb] $1 \cdot 10^{-1}$ M, [Cd] = $1 \cdot 10^{-1}$ M. Tem-r. 473K

No.	CdSb, ml	Sb_2S_5 ml	pH	$CdSb_2S_4$-teorik. mg	$CdSb_2S_4$-exsper. Mg
1	10.00	20	3-4	473.4	348.91
2	10.00	25	«__»	«__»	354.43
3	10.00	30	« »	« »	400.45
4	10.00	35	«__»	«__»	470.90

X-ray phase analysis of cadmium thiostibite obtained in aqueous medium (Mamedova, 2016; 2020; 2020; 2021; Mamedova & Nasirli, 2021; Mamedova, 2021) was performed (Fig. 1). The analysis results confirmed that the sample corresponds to a $CdSb_2S_4$ mixture.

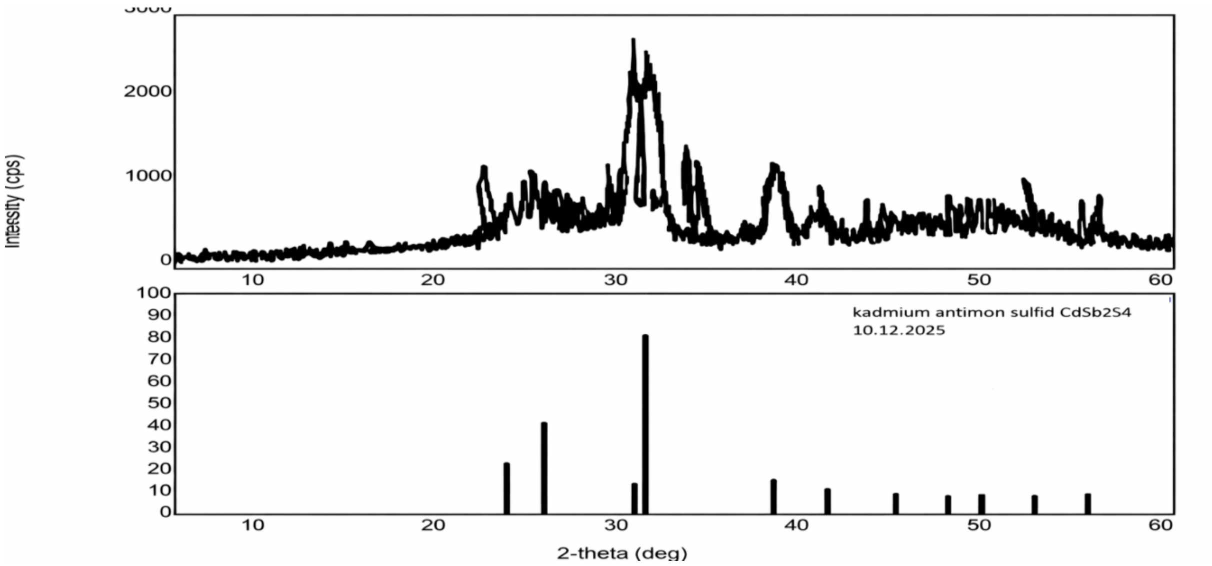

Figure 1. X-ray phase analysis of $CdSb_2S_4$

The strongest peak is observed around 2θ = 30°. This peak represents the main diffraction peak of the $CdSb_2S_4$ crystal. Other peaks are located around 2θ ≈ 27°, 38°, 44°, 48° and 57°. The position of the peaks corresponds to the crystal structure of $CdSb_2S_4$. The intensity of the peaks in the spectrum provides extensive information about the orientation and size of the crystal. The main phase is $CdSb_2S_4$ and there are no additional phases. This indicates that the sample has a tetragonal or orthorhombic structure. Based on the XRD analysis, we can say that the sample has a high crystallinity. Comparison with standard peaks confirms the accuracy of the experimental result. Such $CdSb_2S_4$ materials are promising for photovoltaic and semiconductor applications.

Application field: Cadmium thiostibite has a number of application fields. Table 2 lists the properties, advantages, and uses of cadmium thiostibite (Han, 2022; Zhou, 2013; Yang, 2024).

Table 2
Application area of $CdSb_2S_4$

Application	Area Properties of $CdSb_2S_4$	Advantages / Uses
Optoelectronics	High optical absorption, electron-hole pair separation efficiency	Photodiodes, infrared detectors, improve the performance of optoelectronic devices
Thermoelectric materials	High electronic conductivity, low thermal conductivity	Thermal energy conversion to electricity, energy saving, heat recovery applications
Solar energy technologies	Narrow band gap, photosensitizer property	Buffer or active layer in Sb_2S_3-based solar cells, improves photon absorption and electron-hole separation
Photocatalysis	Catalytic activity under UV and visible light, nanostructured forms	Accelerates water splitting, degradation of organic pollutants, catalysis processes

Discussion

In this study, the synthesis and physicochemical properties of the $CdSb_2S_4$ compound in an aqueous medium were comprehensively investigated. It was determined that $CdSb_2S_4$ can be synthesized with a high yield through the interaction of Sb_2S_5 and CdS obtained from the Daridag ore. The results of X-ray phase analysis confirmed that the sample possesses high crystallinity and that the main phase corresponds to $CdSb_2S_4$. It was observed that increasing the amount of cadmium sulfide leads to a closer agreement between theoretical and experimental results. Chemical analyses verified the stoichiometric composition of the compound and confirmed its formula as $CdSb_2S_4$. The obtained results indicate that $CdSb_2S_4$ is a promising semiconductor material with potential applications in optoelectronics and solar energy technologies.

Conclusion

The effect of the amount of cadmium sulfide on the formation of cadmium thiostibite When increasing the equivalent amount of cadmium Sb_2S_5 at a constant pH value, it was clearly seen that the theoretical and experimental masses overlapped. Chemical analysis confirmed the stoichiometric composition of cadmium thiostibite, and at the same time, its compliance with the formula $CdSb_2S_4$ was determined. The precipitation rate of cadmium thiostibite was calculated and the precipitation time of the reaction was determined. The specificity of the compound was confirmed by X-ray phase analysis.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 61–70
DOI: https://doi.org/10.36719/2707-1146/65/61-70

Comparative Analysis of Nutritional and Biological Values of Whole Wheat Bread with Plant-Based Functional Additives

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Abstract. *This research scientifically and comparatively investigates the dietary and biological significance of traditional whole wheat bread enriched with beet leaf additives. Analyses show that whole wheat bread, being rich in high energy potential (220–240 kcal/100g) and B-group vitamins, meets the basic daily nutritional needs of the human body. On the other hand, incorporating beet leaf homogenate (15–20%) into the formulation significantly increases the product's antioxidant potential, fiber content, and mineral richness (particularly vitamins A, C, and zinc, iron). As a result, while whole wheat bread serves as a classical energy source, the beet leaf additive imparts therapeutic and functional properties to the bread, making it more compatible with modern healthy nutrition standards. Analyses indicate that the incorporation of plant-based components (beet leaf and walnut) enhances antioxidant properties, increases the content of minerals, fats, and dietary fiber, reduces the glycemic index, and improves the digestion process compared to conventional whole wheat bread. Consequently, the inclusion of plant-based functional additives in whole wheat bread significantly improves its nutritional and biological value.*

Keywords: *whole wheat flour bread, beet leaf, bioactive additives, functional food composition, antioxidant effect*

1. Introduction

Bread is one of the staple foods in human nutrition and constitutes an important part of the daily diet in many countries. In particular, bread made from wheat flour is distinguished by its high energy value, good digestibility, and wide availability. Whole wheat bread is widely recognized for its higher nutritional value compared to refined wheat products due to its rich content of dietary fiber, vitamins, and minerals (Carvalho et al., 2018). The nutritional value of bread is closely linked to its chemical composition, the type and grade of flour used, and the characteristics of the technological processing. Certain food additives are used to further enrich the nutritional value of bread. These include some proteins, prebiotics, and certain fibers. These additives, by increasing the nutritional value of bread, improve the digestive process, balance the intestinal microflora, and contribute to overall health. Additionally, high-value bread is a high energy source. This makes it an optimal food source for people engaged in sports, leading physically active lives, and those who prioritize balanced nutrition.

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Received: 7 January 2026; Accepted: 27 March 2026; Published online: 25 April 2026

Numerous studies have highlighted the nutritional value and health benefits of functional foods, showing that diets rich in fruits, vegetables, and other bioactive food components are associated with reduced risk of chronic diseases, including cardiovascular disease, metabolic syndrome, cancer, and obesity (Essa et al., 2021; Asgary et al., 2018; Alissa & Ferns, 2017).

Bread is not only a source of carbohydrates but also a complex food product rich in proteins, B-group vitamins, minerals, and dietary fiber, and its nutrient composition is significantly influenced by the type of flour used (Aghalari et al., 2022). The type of flour used and the degree of processing directly affect the quantity and quality of the food components in the product; bread made from whole grain flour has a higher nutritional potential.

Recent studies indicate that whole wheat breads contain higher levels of dietary fiber, micronutrients (such as B-group vitamins and minerals), and phytochemical compounds compared to bread made from white flour, which contributes to their higher biological and functional nutritional value (Koksel et al., 2023).

This article scientifically compares the nutritional and functional values of whole wheat bread and bread with beet leaf additives, analyzing their main macro- and microcomponents, vitamin-mineral composition, and their significance for the human body. The aim of this study is a comparative analysis of the nutritional and functional characteristics of whole wheat bread and bread with beet leaf additives.

2. Materials and Methods

The main raw materials used in the study were whole wheat flour and beet leaves. Beet leaves were obtained from the Beta vulgaris var. rubra species cultivated in the Aran region of Azerbaijan. The most optimal harvesting period for the use of leaves is considered to be the early vegetation stage, i.e., 30–60 days. At this stage, the plant has not yet fully formed roots, and the leaves are softer, less bitter in taste, as well as richer in vitamins and antioxidant substances. For this reason, the mentioned period is considered the most favorable for both the use of leaves for nutritional purposes and for obtaining bioactive substances at maximum levels. The collection of leaf samples was carried out during the months of May–August of 2025.

Determination of General Chemical Composition

The moisture, ash, and crude protein content of the samples were determined according to the methods of the Association of Official Analytical Chemists (2000). Total lipids were extracted by the Bligh and Dyer method (Bligh & Dyer, 1959). Total carbohydrate content was calculated by the difference method, and the energy value of the product was determined based on the following conversion factors:

- Carbohydrates – 4 kcal/g^{-1} (17 kJ/g^{-1})
- Proteins – 4 kcal/g^{-1} (17 kJ/g^{-1})
- Fats – 9 kcal/g^{-1} (37 kJ/g^{-1})

For the determination of mineral substances, the samples were burned in a muffle furnace at 600 °C for 6–8 hours until complete decomposition of organic matter, and then treated with 5% (v/v) nitric acid solution (approximately 90 °C). The amounts of potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), zinc (Zn), cobalt (Co), manganese (Mn), and sodium (Na) elements were determined using an Analytik Jena novAA 300 flame atomic absorption spectrophotometer (with winAAS software) and the results were expressed in mg/kg. All analyses were performed in triplicate (Biondo et al., 2014).

3. Results and Discussion

1. Nutritional Value of Whole Wheat Bread

1.1 Chemical Composition and Digestibility

Whole wheat bread is considered a well-digestible product. The main reason for this is the structural-mechanical properties of bread and the accessibility of nutrients for digestive enzymes:

- Proteins – in a denatured state;
- Starch – in a partially gelatinized and partially soluble form;
- Fats – emulsified or adsorbed by proteins and starch;
- Sugars and salt – in a dissolved state;
- Bran particles – in a softened form.

The porous structure and soft consistency of bread facilitates its contact with gastrointestinal juices and increases the degree of digestibility.

1.2 Main Nutrients

Proteins and Amino Acids

The protein content in whole wheat bread averages 7.5–8.2%. In terms of biological value, wheat bread is considered somewhat limited because it contains small amounts of certain essential amino acids, particularly lysine, tryptophan, and methionine. At the same time, glutamic acid predominates in the amino acid composition of bread (35–40% of total amino acids). Glutamic acid plays an important role in metabolism, nervous system activity, and improving physical-intellectual performance.

Carbohydrates

The carbohydrate content in wheat bread is 45–50%, of which approximately 80% is in the form of starch. Consumption of 280 g of wheat bread daily can meet approximately 35–40% of the human body's daily energy requirement. Fiber and hemicelluloses, which are of special significance, although not fully broken down, strengthen intestinal peristalsis and regulate the digestive process.

1.3 Vitamin and Mineral Composition

The content of vitamins in wheat bread mainly depends on the grade of flour. In bread made from high-grade wheat flour, vitamins are relatively scarce, because most vitamins are concentrated in the germ and bran layer of the grain. Bread is considered an important source of B-group vitamins (B_1, B_2, PP) in particular. Studies show that as a result of the widespread use of high-grade flour, the level of B-group vitamin intake among the population has decreased by approximately 50% in recent decades. In terms of mineral substances, wheat bread is rich in potassium, phosphorus, magnesium, and iron, but the calcium-phosphorus ratio is not considered optimal.

1.4 Nutritional Value Indicators of Whole Wheat Bread

The evaluation of the nutritional value of bread made from wheat flour is carried out on the basis of an analysis of its chemical composition, energy potential, and the amount of main nutrients. Nutritional indicators are of great importance both in terms of energy supply to the human body and in meeting the daily requirements for proteins, vitamins, and mineral substances. For this purpose, the main indicators of the average chemical composition and vitamin-mineral composition of wheat bread are presented in table form below.

Table 1
Average chemical composition of bread made from whole wheat flour (per 100 g of product)

Indicator	Amount
Energy value	220–240 kcal
Proteins	7.5–8.2 g
Fats	1.0–1.5 g
Carbohydrates	45–50 g
Starch	36–40 g
Dietary fiber	2.0–3.0 g
Water	40–45 g

Table 1 reflects the average chemical composition of bread made from wheat flour per 100 g of product. As can be seen from the data, the energy value of wheat bread ranges from 220–240 kcal, which indicates its high energy potential. This characteristic creates conditions for wheat bread to serve as one of the main energy sources in the daily diet.

The protein content of 7.5–8.2 g confirms the role of bread in partially meeting the body's need for plastic substances. However, since the biological value of proteins is limited by amino acid composition, the co-consumption of wheat bread with other protein-containing products is considered more appropriate.

The carbohydrate content of 45–50 g, including starch of 36–40 g, indicates that wheat bread is primarily a carbohydrate energy source. At the same time, the presence of 2.0–3.0 g of dietary fiber plays an important role in regulating the activity of the digestive system and strengthening intestinal peristalsis. The 40–45% water content of the product is one of the main factors ensuring the soft consistency, good chewability, and high digestibility of wheat bread.

After analyzing the main macrocomponents and energy value indicators of bread made from wheat flour in Table 1, it is considered necessary to evaluate the level of supply of the product with microelements and vitamins. The place of bread in the food diet not only from the point of view of energy and plastic substances, but also according to its vitamin-mineral composition plays an important role in determining its overall nutritional and biological value. In this regard, Table 2 presents the average indicators of wheat bread for main vitamins and mineral substances and scientifically evaluates their role in meeting the physiological needs of the human body.

Table 2
Vitamin and mineral composition of whole wheat bread

Substance	Amount
Vitamin B_1 (thiamine)	0.15–0.20 mg
Vitamin B_2 (riboflavin)	0.05–0.08 mg
Vitamin PP	1.2–1.8 mg
Potassium	120–200 mg
Phosphorus	90–150 mg
Magnesium	20–35 mg
Iron	2.0–3.5 mg

Table 2 presents the level of supply of wheat bread with vitamins and mineral substances. The analysis shows that wheat bread is particularly important as a source of B-group vitamins. The amount of Vitamin B_1 is 0.15–0.20 mg and the amount of Vitamin B_2 is 0.05–0.08 mg. These vitamins play an important role in carbohydrate metabolism, normal functioning of the nervous system, and regulation of energy metabolism.

The level of Vitamin PP at 1.2–1.8 mg shows the positive effect of wheat bread on the activity of enzyme systems participating in oxidation-reduction processes.

In terms of mineral substances, wheat bread is richer in potassium (120–200 mg) and phosphorus (90–150 mg). Potassium performs important functions in the activity of the cardiovascular system, and phosphorus in the formation of bone tissue and energy metabolism. The presence of magnesium (20–35 mg) and iron (2.0–3.5 mg) further increases the importance of this product from the perspective of neuro-muscular conduction and hematopoiesis processes. It should also be noted that the amount of mineral substances in wheat bread varies depending on the grade of flour, and these indicators are relatively lower in breads made from high-grade flours.

1.5 Digestibility and Hygienic Evaluation of Whole Wheat Bread

In wheat bread, protein digestibility typically ranges between 75–85%, while carbohydrate digestibility reaches 95–98%, reflecting its high nutritional quality (Rosas-Rivas et al., 2025). From a hygienic standpoint, quality wheat bread should have a smooth surface, uniform porous internal structure, pleasant aroma, and taste, with moisture content not exceeding 42–45% (Zeng et al., 2024). Porosity generally varies within the normal range of 45–75%, which is crucial for both sensory properties and digestibility. Scientific analyses indicate that bread made from wheat flour is one of the main food products providing high energy value, good digestibility, and important functional significance in daily diets (Zeng et al., 2023). Bread plays a key role in supplying proteins, B-group vitamins, minerals, and dietary fiber, alongside being a primary source of carbohydrate energy. The nutritional value of wheat bread is directly related to the type and grade of flour used. While breads made from high-grade flours exhibit superior technological and sensory characteristics, whole grain and low-grade flours contribute higher dietary fiber, microelements, and biologically active compounds, highlighting their importance as functional food products. Structural and mechanical properties, along with the porous architecture of wheat bread, ensure a high level of nutrient digestibility, reinforcing its hygienic and physiological advantages. In this context, flour enrichment, application of functional additives, and optimization of technological processes are promising approaches to enhance the nutritional and biological value of wheat bread (Rosas-Rivas et al., 2025; Zeng et al., 2024; Zeng et al., 2023).

2. Nutritional Value of Bread with Beet Leaf and Walnut Additives

In contemporary food production, one of the key goals is to enhance product quality. The quality of bread and other flour-based products is influenced by their nutritional profile, sensory attributes, and appearance, which in turn depend on the selection of raw materials, processing methods, and storage conditions. Recently, incorporating beet leaf and other vegetable powders into bread has become increasingly popular in functional food production. These plant-based additives can boost the content of vitamins, minerals, dietary fiber, and antioxidants, while also contributing to a more balanced energy profile.

The objective of this study is to assess the nutritional characteristics of bread prepared with beet leaf supplementation and to evaluate its potential as a functional food product. Bread samples were prepared using a traditional recipe, and experimental variants were produced by including beet leaf homogenate at levels of 15–20%. The balance of proteins, carbohydrates, and fats was analyzed, while the energy value and macronutrient composition were determined through laboratory measurements and standard reference data. The vitamin and mineral content was estimated by considering the contribution of the beet leaf additive to the overall nutritional profile.

Table 4
Nutritional and energy value of bread with beet leaf and walnut additive (per 100 g of product)

Indicator	Amount	Significance
Energy value	258.4 kcal	Approximately 12.9% of daily energy requirement.
Proteins	8.2 g	Increased due to whole wheat flour and walnut; plastic material for muscle tissue.
Fats	11.8 g	High due to walnut and vegetable oil; source of Omega-3 and Vitamin E.
Carbohydrates	31.5 g	Complex carbohydrates from whole wheat flour; stable energy supply.
Dietary fiber	5.4 g	High-fiber product. Regulates digestion due to beet leaf and whole wheat flour.
Moisture (Water)	43.1 g	High due to beet puree; ensures softness and freshness of bread.

This table shows that the energy value of 100 g of the finished product was determined to be 258.4 kcal, which meets approximately 13% of the daily energy requirement. The macrocomponent composition of the product fully meets functional food standards: protein content enriched with whole wheat flour and walnut at 8.2 g, and fat content increased to 11.8 g (this increase is mainly due to beneficial Omega-3 fatty acids from walnut).

The dietary fiber content, which is the most important functional indicator of the product, is 5.4 g; this indicator was created as a result of the synergistic effect of beet leaf and whole wheat flour and falls into the high-fiber product category that strengthens intestinal peristalsis. The complex structure of carbohydrates (31.5 g) and high moisture content (43.1 g) both lower the glycemic index of bread and ensure its long-term freshness.

Table 5
Vitamin and mineral composition of bread with beet leaf and walnut additive (per 100 g of product)

Substance	Amount (approx.)	Physiological Significance
Vitamin A	180–260 µg	Vision, immune system and skin health (from leaf).
Vitamin B_1	0.18–0.25 mg	Carbohydrate metabolism and nervous system (whole wheat flour).
Vitamin B_2	0.12–0.18 mg	Energy metabolism, skin and eye health.
Vitamin PP	2.2–3.0 mg	Energy metabolism and enzyme systems activity.
Vitamin C	10–18 mg	Antioxidant and iron absorption (leaf and beet).
Calcium	95–150 mg	Bone and dental health, blood coagulation.
Phosphorus	150–220 mg	Cellular energy and bone formation.
Potassium	310–420 mg	Cardiovascular system and water-salt balance.
Magnesium	55–85 mg	Neuro-muscular function (walnut and whole wheat).
Iron	4.2–5.5 mg	Hemoglobin formation and hematopoiesis.
Zinc (Zn)	1.5–2.4 mg	Immunity and cell recovery.

The vitamin and mineral profile per 100 grams of the beet-leaf and walnut bread under study demonstrates high functionality. Vitamin A (180–260 µg) and Vitamin C (10–18 mg) in the product's composition are mainly supplied by beet leaf, creating a powerful antioxidant effect that strengthens the immune system. The bran portion of whole wheat flour enriches the product with B_1 (0.18–0.25 mg) and PP (2.2–3.0 mg) vitamins, turning it into a significant source for nervous system and energy metabolism.

In terms of mineral composition, the bread supports the functioning of the cardiovascular system with high Potassium (310–420 mg) and Magnesium (55–85 mg) content. In particular, the Iron (4.2–5.5 mg) and Calcium (95–150 mg) content coming from beet leaf increases the biological value of the product for hematopoiesis and bone health. The presence of Vitamin C in the composition stimulates the absorption of plant-based iron, ensuring the effectiveness of the product in the prevention of anemia.

2.1 Bioactive and Functional Properties

Beet leaf has high antioxidant activity. Beta-carotene and lutein/zeaxanthin compounds protect cells from the damage of free radicals and reduce the risk of chronic diseases. Additionally, since the tops are a natural source of nitrates, they help regulate blood pressure, protect cardiovascular health, and strengthen detoxification processes. The fibers in its composition support intestinal function and promote a healthy microbiome (Kuznetsova & Sidanova, 2020).

2.2 Functional Advantages of the Product

Bread with beet leaf additive provides the following advantages:

– Improves energy and macronutrient balance;
– Increases vitamin and mineral supply;
– Exhibits antioxidant and anti-inflammatory effects;
– Supports cardiovascular and digestive systems;
– Suitable for use in daily diet as functional food.

Thus, the beet leaf additive not only changes the color and taste characteristics of bread, but also significantly increases its nutritional and functional value. This product is particularly recommended for consumers who choose a healthy lifestyle and prefer functional nutrition.

Research shows that beet leaf additive increases the nutritional value of bread and can be used as a functional food product. The most appropriate dosage is 10–15% by volume; at this point, both the nutritional composition is enriched and the organoleptic indicators of the product are maintained. Bread prepared with beet leaf additive can be recommended for healthy nutrition, especially by increasing fiber, vitamin and mineral balance (Kuznetsova & Sidanova, 2020).

3. Comparative Analysis of Whole Wheat Bread and Bread with Beet Leaf and Walnut Additives

Both whole wheat bread and bread with beet leaf additives serve as the main sources of energy and nutrition in the daily diet, but their nutritional and functional values differ in several respects. Whole wheat bread stands out with its high energy value (220–240 kcal/100 g), protein (7.5–8.2 g), carbohydrate (45–50 g), and dietary fiber (2–3 g), and is also rich in B-group vitamins and macroelements (potassium, phosphorus, magnesium, iron). Its biological value is related to the balance of amino acids and the effectiveness of protein digestion (75–85%), and its low glycemic index demonstrates its advantage as a functional food.

Although bread prepared with beet leaf additive is similar in terms of main food components, its functional characteristics are significantly increased. With a 10–15% additive, vitamins A and C, antioxidants, minerals (calcium, zinc, phosphorus, magnesium), and dietary fiber are enriched. This additive, by increasing the anti-inflammatory and antioxidant activity of bread, supports immunity, improves cardiovascular system and intestinal function. The macronutrient balance and energy supply are also maintained at an optimal level. Table 6 presents a comparative analysis of whole wheat bread and bread with beet leaf additive.

Table 6

Comparative analysis of whole wheat bread and functional (beet leaf + walnut) bread

Parameter	Standard Whole Wheat Bread	Beet Leaf & Walnut Bread	Scientific Note
Energy value (kcal/100 g)	220–240	258.4	Higher energy density due to walnut and fat.
Protein (g/100 g)	7.5–8.2	8.2	Walnut plant proteins complement whole wheat flour.
Fat (g/100 g)	1.5–2.5	11.8	Rich in Omega-3 and unsaturated fatty acids.
Carbohydrate (g/100 g)	45–50	31.5	Lower carbohydrate load as flour amount is reduced.

Dietary fiber (g/100 g)	2.5–3.5	5.4	Twice the fiber content thanks to leaf fiber.
Vitamins & minerals	B_1, B_2, PP, Mg, Fe	A, C, B-group, Fe, Ca, K, Zn	Beet leaf provides advantage in Vitamin A, C and Calcium.
Glycemic Index (GI)	55–65 (Medium)	45–50 (Low)	High fiber and fat slow down carbohydrate absorption.
Antioxidant profile	Low / Medium	High	Due to betalains in leaf and polyphenols in walnut.

The comparative analysis shows that the proposed functional bread has a sharp advantage over standard whole wheat bread in terms of micronutrients (vitamin-mineral) and biologically active substances. The carbohydrate content of the product decreased by approximately 30%, while the dietary fiber content doubled; moreover, previous studies have shown that the incorporation of plant-based components enhances antioxidant properties and increases dietary fiber content compared to conventional whole wheat bread (Sławińska et al., 2022). Which proves its effectiveness in diabetic and dietary nutrition. In particular, the presence of Vitamins C and A, providing the product with anti-anemic and antioxidant properties, elevates it to a higher functional category than whole wheat bread. Comparative analysis and other studies also indicate that the enrichment of bread with plant-based functional additives has a positive effect on reducing its glycemic index and improving the digestion process (Liu et al., 2022).

Thus, both products complement each other: while whole wheat bread provides basic nutritional support, bread with beet leaf additive meets the requirements of modern dietary and healthy nutrition by increasing both nutritional and functional advantages. This comparison creates a scientific basis for strategic choices in both classic and functional bread production.

Conclusion

As a result of the research conducted, it was determined that whole wheat bread occupies an important place in daily nutrition by being rich in high energy and basic nutrients. The beet leaf additive, by increasing the vitamin, mineral, and antioxidant composition of bread, strengthens its functional food characteristics. The most optimal additive amount is considered to be 10–15%. At this point, both the nutritional value increases and the organoleptic characteristics are preserved. Thus, these two products, complementing each other, create a balanced nutritional source both in terms of energy and health, and are in line with the modern concept of healthy nutrition.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 71–76
DOI: https://doi.org/10.36719/2707-1146/65/71-76

Quality Characteristics of Quil and Broiler Meat Stored Under Hot Climate Conditions

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Abstract. *This study aims to comparatively evaluate the meat quality characteristics of broiler (Ross-308) and quail (White English breed) raised under hot climatic conditions. With the increasing demand for animal-derived food products, the development of poultry production has become essential. Although broiler meat remains widely consumed, interest in quail meat has grown significantly in recent years due to its high nutritional value. In this study, quails were slaughtered at 42 days of age, while broiler chickens were slaughtered at 35 days. A comparative analysis of breast, thigh, and wing muscles was conducted. The scientific novelty of the research lies in the fact that, for the first time, a comprehensive and systematic comparative evaluation of these specific muscle groups in broiler and quail has been carried out. Moisture content was determined using a thermostat method, protein content by the Kjeldahl method, fat content by the Soxhlet extraction method, and ash content using a muffle furnace. Sensory evaluation of meat and broth samples was performed by a five-member panel using a 9-point scale. Meat freshness and pH values were also assessed. The results indicate that quail meat demonstrates superior quality indicators compared to broiler meat in terms of nutritional value. Moreover, quails exhibit greater resistance to temperature stress, making them more suitable for hot climates. These findings support the expansion of quail production as an economically viable and sustainable alternative.*

Keywords: *quil, White English breed, Ross 308, muscle, breast meat*

Introduction

In recent years, the demand for poultry meat in our republic has been steadily increasing. The population predominantly consumes broiler chicken meat. However, depending on the season, particularly during autumn and winter, the demand for turkey, goose, duck, and quail meat also rises (Taghiyev, 2023; Taghiyev, 2024).

As is well known, Azerbaijan encompasses 9 out of the 11 climatic zones observed worldwide. In the research regions studied, high temperatures during the summer months lead to the persistent occurrence of heat stress. These conditions negatively affect the quality of meat obtained from poultry. Other researchers (Kim & Lee, 2023, pp. 689–712) have also demonstrated that hot climatic conditions adversely influence both the clinical and physiological state of poultry and the productivity of meat obtained from them.

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Received: 19 December 2025; Accepted: 23 March 2026; Published online: 25 April 2026

One of the main factors negatively affecting the health of quail and broiler birds is heat stress. When temperatures rise excessively, the metabolic processes of birds are disrupted, and feed intake decreases. Under heat stress conditions, the respiratory process of birds is also impaired. As a result, blood pH levels increase, while CO_2 levels decrease. These changes lead to the development of respiratory alkalosis caused by hyperventilation.

Researchers indicate that quails are more resistant to heat stress compared to broiler chickens (Ribeiro et al., 2024, pp. 3–16). Quail meat is characterized by a high content of amino acids, particularly tryptophan, leucine, alanine, and methionine. In contrast, broiler chickens contain lower levels of unsaturated fatty acids. Quail meat is rich in polyunsaturated and monounsaturated fatty acids, especially linolenic and linoleic acids (Kokoszyński et al., 2024, pp. 2–4).

During heat stress, the level of lysozyme in the organism of birds decreases. In recent years, as in many other countries, interest in the consumption of quail meat has significantly increased in our republic. Researchers working in this field (Mammadova, 2024) note that, for meat production purposes, breeds such as White Texas, Pharaoh, as well as dual-purpose breeds including Manchurian, Estonian, and White English quails are raised both in Azerbaijan and in other countries.

However, due to the white color of the meat and the ability to produce up to 280 eggs per year, farmers and household producers most commonly prefer the White English breed (Abdilkhalikova, 2014).

The occurrence of various diseases among quails and broiler chickens raised under hot climatic conditions affects the quality of meat obtained from them in the future. In broiler production, the housing system has a direct impact on the pH values of the meat. It has been observed that the texture of meat obtained from birds raised in cage systems is of higher quality compared to that of birds raised in floor-based systems. However, in broiler chickens raised under cage systems, diseases such as leg fatigue are observed more frequently. The protein contained in broiler meat is essential for the human body. The housing system used in poultry production plays a crucial role in terms of both productivity and meat quality. Significant differences in meat quality are observed when broiler chickens are reared under different housing systems.

While quails raised in cage systems tend to have higher live body weight, the meat of birds raised on litter systems, despite having lower live weight, exhibits higher nutritional value due to its chemical composition (Wegner et al., 2024, pp. 5–8; Wang et al., 2021, pp. 2–8). Studies conducted in this field have shown that diseases affecting the reproductive organs in both quails and broiler chickens lead to a decrease in breast meat yield. Numerous researchers have demonstrated that when various feed additives are incorporated into the diet, quails exhibit better performance outcomes compared to broiler chickens. One of the important factors influencing the main characteristics of quail meat is the supplementation of feed with ginger powder and frankincense oil. These substances directly affect metabolic processes in the organism as well as the chemical composition of the meat. Their application contributes to enhancing the nutritional value of quail meat (Mohamed et al., 2024, pp. 4–5).

Methods

The research was conducted during 2024–2025 in the poultry housing facility located in the vivarium of the Azerbaijan State Agrarian University (ASAU), as well as under a shed during the summer months. The study was carried out on White English breed quails and Ross-308 broiler chickens, which are the most commonly reared and consumed poultry types in Azerbaijan.

During slaughter, the breast, thigh, and wing muscles of the quails were separated, and their weights and chemical characteristics were determined. Slaughtering of the quails was performed at 42 days of age. In order to assess meat quality, five quails were slaughtered in each trial, and analyses were conducted on these samples. The same procedures were applied to Ross-308 broiler chickens; however, slaughter was carried out at 35 days of age.

During the study period, to determine the moisture content of the meat, the initial weight of the samples was first measured. Subsequently, the meat was kept in a thermostat for 20 minutes, after which it was reweighed, and the moisture content in the muscle tissue was calculated based on the difference. The protein content was determined using the Kjeldahl method, while the fat content was analyzed using the Soxhlet method (GOST, 2019).

The ash content of the meat was determined after incineration in a muffle furnace. The quality of quail meat under conditions of heat stress was studied both indoors and under a shed, considering birds reared in cage systems as well as on litter. In order to clarify the differences between quail and broiler meat, the same experimental conditions were also applied to Ross-308 broiler chickens.

The quality indicators of meat and broth obtained from quails and broiler chickens were determined at the Department of Hygiene and Food Safety of the Azerbaijan State Agrarian University (ASAU). A panel consisting of five staff members of the department was formed to conduct the sensory evaluation. The quality of the meat and broth was assessed using a 9-point scoring system.

The analysis of the chemical composition of quail and chicken meat was also carried out in the laboratory of the Livestock Scientific Research Institute (LSRI) on 25 April 2025 and was formalized under expert protocols No. 1080, 1081, and 1082.

For the evaluation of the economic efficiency of the obtained results and their statistical analysis, Microsoft Excel and SPSS 20 software packages were used. The level of statistical significance was considered at $P > 0.5$.

Results and Discussion

At the initial stage of the study, five quails from each group were slaughtered at 42 days of age in the ASAU vivarium, and their productivity indicators were determined. The results showed that the carcass weight of quails reared on the floor was 183 ± 2.02 g, whereas those kept in cages reached 186.6 ± 1.86 g. The breast muscle weight was 69.6 ± 0.16 g in floor-reared quails and 70.7 ± 0.58 g in cage-reared birds. Thigh muscle weights were 27.7 ± 0.84 g (floor) and 28.04 ± 0.73 g (cage), while wing muscle weights were 15.2 ± 0.04 g and 15.8 ± 0.01 g, respectively.

However, all indicators were higher in quails kept under a canopy, both in cages and on litter. The highest values were recorded in birds reared in cages under the canopy: breast muscle 86.5 ± 0.24 g, thigh muscle 31.4 ± 0.17 g, and wing muscle 16.4 ± 0.09 g. These findings indicate that cage rearing under a canopy leads to higher meat yield in quails. Chemical analysis of muscle tissues showed that samples obtained from cage-reared quails contained 72.03% moisture, 20.66% crude protein, 6.18% crude fat, and 1.13% crude ash (sample No. 1080; analyses conducted at the LRI laboratory).

Sensory evaluation revealed that breast meat from quails reared on the floor under a canopy received scores of 8 for aroma, 8 for taste, 7 for texture, and 7 for juiciness on a 9-point scale. In contrast, meat from cage-reared quails scored higher: 9 for aroma, 8 for taste, 9 for texture, and 9 for juiciness.

The broth prepared from quail meat obtained from cage-reared birds under a canopy was rated 9 for aroma, 8 for taste, 8 for consistency, and 9 for juiciness. For birds reared on the floor under a canopy, the corresponding scores were 8, 9, 9, and 6. Overall, both meat and broth from quails were considered highly suitable and valuable for human consumption regardless of rearing conditions. The chemical composition of meat from Ross-308 broilers reared under a canopy was 71.6% moisture, 20.4% crude protein, 5.9% crude fat, and 2.1% crude ash. The fat content in broiler meat was lower than in quail meat by 0.28%.

An important aspect of meat quality is resistance to chemical reactions, as well as suitability for consumption and freshness. The results of freshness tests using copper sulfate and formalin reactions are presented in Table 1. The analyses showed that both quail and broiler meat gave negative results in the copper sulfate test, indicating no color change. The formalin reaction was also negative for both types, confirming their freshness and quality. However, when stored at room temperature for extended periods, changes in freshness were observed. In some cases, broiler meat showed positive reactions, whereas quail breast and thigh meat remained negative (Table 1).

The pH values of the meat were also determined: 6.7 in broilers and 6.9 i The pH values of the meat were also determined: 6.7 in broilers and 6.9 in quails; these values are critical as post-mortem pH decline is directly linked to chronic heat stress and the subsequent oxidative stability of the muscle tissue (Liu et al., 2022). According to Oluwagbenga & Fraley (2023), heat stress-induced glucocorticoid secretion can alter post-mortem glycolysis and pH decline, ultimately affecting meat quality parameters such as water-holding capacity and tenderness. In both types, pH decreased with longer storage time.

Table 1
Determination of freshness of quail and broiler meat (N = 5)

Indicators	Quail – White English (Cage)	Quail – White English (Floor)	Broiler – Ross 308 (Cage)	Broiler – Ross 308 (Floor)
Copper sulfate (12 h)	Negative	Negative	Negative	Negative
Copper sulfate (24 h)	Negative	Negative	Positive	Positive
Formalin (12 h)	Negative	Negative	Negative	Negative
Formalin (24 h)	Negative	Negative	Negative	Positive
Peroxidase reaction	Positive	Positive	Positive	Positive
pH	6.9	6.9	6.7	6.7

The results of the study demonstrated that quails reared in cages, particularly under a canopy, exhibited higher meat productivity and superior quality characteristics. Chemical analysis confirmed that quail meat contained higher levels of crude fat and protein compared to broiler meat, supporting its classification as a higher-quality product.

The comparison of pH values showed that quail meat (pH 6.9) has a less acidic environment than broiler meat (pH 6.7), which indicates better storage stability. Freshness tests further confirmed the superiority of quail meat: while broiler meat showed positive reactions after storage, quail meat remained negative. This indicates greater resistance to spoilage and higher biological quality. The observed differences in meat quality between quails and broilers may also reflect differential immune and physiological responses to heat stress; quails may exhibit greater resilience as evidenced by fewer changes in immune organ integrity and lower susceptibility to oxidative damage (Oluwagbenga & Fraley, 2023).

Overall, the higher fat content, more stable pH, and sustained negative freshness reactions demonstrate that quail meat is of higher quality, more resistant to storage conditions, and safer from a veterinary-sanitary perspective than broiler meat. For the first time, this study comparatively evaluated the physicochemical properties of muscle tissues in quail and broiler carcasses. The findings clearly indicate that, based on these parameters, quail meat is more suitable for human nutrition.

Conclusion

The findings confirm that under hot climate conditions, heat stress directly affects the physical and chemical properties of poultry meat, significantly influencing productivity and overall quality. In this context, quails demonstrate greater tolerance to heat stress compared to broiler chickens, whose physiological condition and productivity are negatively impacted under the same environmental conditions. The study shows that quail meat has superior physicochemical characteristics, including higher protein and fat content, as well as better sensory properties, making it more valuable for human nutrition. Freshness tests using copper sulfate and formalin indicate that both quail and broiler meat are initially fresh; however, during prolonged storage at room temperature, broiler meat exhibits signs of deterioration, whereas quail meat remains stable. The higher pH stability and resistance to spoilage observed in quail meat further confirm its better storage properties and higher biological quality. Overall, the comparative analysis demonstrates that quail meat is more resistant to heat stress, possesses higher quality indicators, and is more suitable for safe and nutritious human consumption than broiler meat.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 77–82
DOI: https://doi.org/10.36719/2707-1146/65/77-82

Development of Some Medicinal Plants Under the Agroecological Conditions of the Ganja–Gazakh Region

Afag Aliyeva

Abstract. *The article provides information on innovative methods for cultivating medicinal plants in the Ganja–Gazakh region, which has favorable climatic conditions for agriculture, as well as their potential application within the region's agroecological environment. As is known, medicinal plants are widely used in traditional medicine, the pharmaceutical industry, cosmetology, and other fields. The cultivation of these plants in the Ganja–Gazakh region plays an important role, particularly in providing income for the rural population. The use of innovative technologies in the cultivation of medicinal plants is important not only for increasing productivity but also for ensuring ecological safety. Soil sample analysis shows that the soils are insufficiently supplied with available forms of nitrogen, phosphorus, and potassium. These soils are generally poorly provided with nutrients. Therefore, the application of organic and mineral fertilizers is essential to ensure the growth, development, and high yield of agricultural crops, as well as to maintain soil fertility. Observations conducted on Achillea filipendulina demonstrated that the duration and percentage of germination vary depending on soil moisture and temperature conditions. In the case of Taraxacum officinalis, seeds sown under certain agrotechnical conditions show higher productivity in the third year. Experimental results have established that the application of different rates of mineral fertilizers in combination with manure significantly increases the number of vegetative and generative shoots per plant.*

Keywords: *medicinal plants, agroecology, innovative methods, organic fertilizers, mineral fertilizers*

Introduction

The Ganja–Gazakh region is one of the most productive and actively cultivated regions of Azerbaijan. It possesses favorable climatic conditions for agriculture. This region has unique soil and water resources, which make it ideal for cultivating medicinal plants. Due to their pharmaceutical value, medicinal plants have played an important role in the development of agriculture in recent years (Krommelin et al., 2019; Behera et al., 2017; Dhakad et al., 2017).

The use of innovative technologies makes it possible to increase efficiency in the cultivation of medicinal plants, improve quality, and enable harvesting without harming the ecosystem. This article examines innovative methods for cultivating medicinal plants in the Ganja–Gazakh region and their potential application under the region's agroecological conditions.

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Received: 13 January 2026; Accepted: 15 March 2026; Published online: 25 April 2026

Medicinal plants are widely used in traditional medicine, the pharmaceutical industry, cosmetology, and other fields. The cultivation of these plants in the Ganja–Gazakh region plays an important role in providing income, especially for the rural population. This region is one of the most favorable agricultural areas of Azerbaijan. Its agroecological conditions, including climate, soil, and water resources, are suitable for growing medicinal plants.

The use of innovative technologies in the cultivation of medicinal plants is important not only for increasing productivity but also for ensuring ecological safety. Therefore, considerable attention is paid to studying the effectiveness of innovative technologies in agriculture. In his work "Agroecological Technologies and Innovative Approaches" (2021), Kuyukov examines the application of innovative methods in agriculture. He argues that modern technologies such as hydroponics, aeroponics, and smart irrigation systems play a significant role in preserving soil fertility and ensuring the efficient use of water resources (Labashchi, 2017; Muhammadjonova et al., 2022; Šarćević Todosijević et al., 2019; Sen & Samanta, 2014). The application of these technologies in the cultivation of medicinal plants in the Ganja–Gazakh region can significantly increase productivity.

The Ganja–Gazakh region is located in the western part of the republic and is characterized by a dry and semi-dry climate with a moderately warm steppe type. Summers are hot, while winters are dry and mild, with unstable snow cover. The average annual temperature is 11.8–13.1 °C. In the lowland semi-zone, at an altitude of 69–450 meters above sea level, the sum of active temperatures reaches 4000–5000 °C, and annual precipitation ranges from 252 to 294 mm. In the foothill and mid-mountain semi-zones, at altitudes of 600–1200 meters above sea level, the average annual temperature is 10.3–11.8 °C, the sum of active temperatures is 3200–3700 °C, and precipitation ranges from 346 to 525 mm. The cold period of the year lasts from November to March. The coldest month is January, while the average summer temperature is 23–25 °C.

In the Ganja–Gazakh region, groundwater lies deep and does not participate in soil formation processes. In the mountainous, central, and western parts of the region, natural soil drainage, combined with intensive irrigation, leads to the mineralization of groundwater, which gradually increases from the mountainous areas toward the Kura River. In the eastern part of the region, sulfate-sodium and chloride-sulfate mineralization dominates in groundwater. According to Professor M. E. Salayev, dry, dark gray-brown (chestnut) soils are widespread in the Ganja–Gazakh plain.

Water resources in the Ganja–Gazakh region are extremely important for agriculture. However, their efficient management and economic use have become a pressing issue. Smart irrigation systems, such as automated irrigation, help reduce water loss and allow for more precise forecasting of crop moisture requirements.

Materials and Methods

The systematic position of the species was determined according to generally accepted principles, including APG IV (World Flora Online Consortium, 2012), World Flora Online **(**Angiosperm Phylogeny Group, 2016), and The Euro+Med PlantBase through which the taxonomy and nomenclature of the species were clarified. In studying the bioecological characteristics of the species, the following sources were used: Flora of Azerbaijan (Grossheim, 1945; Flora of Azerbaijan, 1952), Plant World by A. M. Asgarov (2016), Volume III of Conspectus of the Flora of the Caucasus (2012), as well as works by other researchers (Bayramova et al., 2025).

The experiments were conducted in dry soil conditions in the Ganja–Gazakh region. Field experiments were established as a three-factor design (3 × 3 × 5) according to the following scheme:
Factor A – Sowing time: 1) April 1–5; 2) April 10–15; 3) April 20–25

Factor B – Planting scheme: 1) 45 × 5 cm spacing, plant density 440,000 plants/ha; 2) 45 × 10 cm spacing, plant density 220,000 plants/ha; 3) 45 × 15 cm spacing, plant density 148,000 plants/ha
Factor C – Fertilizer rates: 1) Control (no fertilizer); 2) Manure 10 t/ha (basal application); 3) Basal + N30P60K30; 4) Basal + N60P90K60; 5) Basal + N90P120K90

Table 1
Agrochemical Properties of Soils in the Experimental Area

			Azot			Fosfor		Kalium	
Depth, cm	pH water	Total humus, %	Total, %	Absorbed ammonia, N/NH_3 mq/kq	Nitrate nitrogen, N/NO_3 mq/kq	Total, %	Mobile, mq/kq	Total, %	Exchangeable, mq/kq
0-30	7,8	2,15	0,15	18,0	9,7	0,13	16,8	2,39	263,5
30-60	8,2	1,17	0,09	15,3	6,4	0,09	13,8	1,85	201,0
60-100	8,4	0,85	0,06	6,5	2,6	0,07	4,5	1,51	105,3

Results and Discussion

The analysis of soil samples showed that the soils are poorly supplied with available forms of nitrogen, phosphorus, and potassium. These soils are characterized by a low level of nutrient availability. Therefore, the application of both organic and mineral fertilizers is essential for ensuring the growth and development of agricultural crops, achieving high yields, and maintaining soil fertility.

Achillea filipendulina Lam. is characterized by a wide range of biologically active compounds, which determine its diverse pharmacological effects. The plant primarily possesses hemostatic properties. The herb exhibits anti-inflammatory, antiallergic, bactericidal, and wound-healing effects, which are associated with the presence of azulenes, tannins, and flavonoids.

The plant is used to relieve spasms of the stomach, intestines, bile ducts, and urinary tract. It is included in appetite-stimulating and anti-hemorrhoidal preparations. In cases of gastric and duodenal ulcers, ulcerative colitis, acute and chronic dysentery, hepatitis, cholecystitis, and angiocholitis, an infusion of yarrow (20:200) is used—1 tablespoon 3–4 times daily after meals.

Between 2022 and 2025, studies were conducted on the germination, propagation, and cultivation of *Achillea filipendulina* (Fig. 1). The ontogenesis of the plant was observed. Seeds of this species were collected from natural habitats.

The seeds are brown in color, and the weight of 1000 seeds is 0.53 g.
During the experiments: Seeds were sown in open field conditions from February to June; sowing was repeated every 15 days; soil temperature and moisture levels were monitored until germination.
The observations showed that germination time and percentage vary depending on soil moisture and temperature.

Optimal Conditions for germination – soil moisture: ≤ 35%; temperature: 10–20 °C
Effect of Temperature on germination – at 15 °C → germination occurs in 19–20 days; at 20 °C → germination occurs in 10–12 days.

Germination Rate Depending on Temperature at 10 °C → 20–25%; at 15 °C → 50–60%; at 20 °C → 80–82%.
Effect of sowing depth on germination – 3 mm → 75–80%; 5 mm → 60–65%; 7 mm → 40%; 10 mm → 10–12%
Germination time by depth 3 mm → ~20 days; 5 mm → ~17 days; 7 mm → ~5 days (≈40% germination); 10 mm → ~7 days (≈25% germination).

- Germination is strongly dependent on temperature and moisture, indicating sensitivity to environmental conditions
- Optimal germination occurs at moderate temperature (≈20 °C) and controlled moisture.
- Shallow sowing (≈3 mm) provides the highest germination rate.
- Increasing depth significantly reduces germination percentage due to: oxygen limitation; mechanical resistance of soil

Figure 1
Achillea filipendulina Lam.

In the Ganja–Gazakh region, optimal conditions for normal germination of *Achillea filipendulina* seeds require soil moisture of 35% and a temperature of 20 °C. Seeds should be sown at a depth of 3 mm and within a 10-day period, no later than March 14.The cotyledon leaves emerging from the seeds are elongated in shape; under open field conditions, their length is 2.76 mm and width is 1.62 mm. The petiole length is 1.89 mm, and its color is dark purple. The virginal stage lasts until the end of April.The first true leaves are segmented, pinnate, and elongated lanceolate in shape, with a purple-violet color. The petiole length is 2.09 mm. The next two leaves are pinnately lobed, with a length of 2–12 mm and a width of 1–8 mm.The stem is usually single, straight, and erect; it is woolly-hairy in the lower part and branched, while the upper part is glabrous. Mature leaves have a length of 6–17 mm and a width of 2–6 mm. The involucre is lanceolate and pointed, with a length of 3 mm. The receptacle length is 4.5–5 mm, and its width is 2–3 mm. Observations show that the first flowering period begins in the second decade of May and continues until the end of August. Seeds ripen in August and September.

Taraxacum officinale leaves are rich in vitamins A, C, and K, as well as minerals such as potassium and iron. This plant can be used to support liver function and promote the elimination of toxins from the body. Due to its mild diuretic effect and its ability to stimulate appetite, it helps alleviate problems such as constipation and bloating. It also contains antioxidant compounds that help combat stress and reduce the risk of chronic diseases. *Taraxacum officinale* propagates by seeds (Figure 2). The seeds were collected together with their pappus.

Figure 2
Taraxacum officinale

The seeds are light brown in color, and the weight of 1000 seeds ranges from 0.25 to 0.96 g.The conducted experiments showed that when seeds of medicinal dandelion (*Taraxacum officinale*) are sown at a depth of 10 mm and at a temperature of 15–20 °C, they achieve up to 80% germination within 7 days. Seeds sown at a temperature of 10–12 °C show 65–70% germination after 9 days. Thus, for normal germination of dandelion seeds, the optimal soil temperature should be in the range of 8–10 °C. For transplanting seedlings, the row spacing should be 25 cm, and the distance between plants should be 15 cm. Seeds sown in autumn flower and produce seeds in the spring of the following year. Seeds sown in spring produce flowers and seeds in the autumn of the following year. Plants grown from sown seeds reach their highest productivity in the third year.

Conclusion

The conducted experiments demonstrated that the application of different rates of mineral fertilizers in combination with manure significantly increased the number of vegetative and generative shoots per plant. In the treatment basal + N30P60K30 under the planting scheme of 45×5 cm, the seed yield per plant was 15.5–16.2 g and 140.3–142.7 g (note: clarify units/interpretation in final manuscript if needed). The highest values were observed in the treatment basal + N60P90K60 under the same planting scheme (45 × 5 cm).

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 83–89
DOI: https://doi.org/10.36719/2707-1146/65/83-89

Soil Pollution and Agricultural Productivity Losses

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Abstract. *In the modern era, soil pollution is considered one of the main threats to the sustainability of agricultural ecosystems. In particular, under intensive cultivation conditions, changes in the physical and agrochemical properties of soils significantly affect the yield and quality of agricultural crops. The aim of the present study was to assess the level of soil pollution in the sugar beet fields of Azershakar LLC in Yevlakh district, to evaluate its effects on the physical and agrochemical properties of the soil, and to investigate the relationships between these changes and crop yield and sugar content. During the study, soil samples were collected from plots with varying levels of pollution, and the analyses were conducted in accordance with international ISO standards. The results indicated that increasing levels of pollution led to the deterioration of soil structure, a reduction in humus content, a deficit of essential nutrients, and accumulation of sodium. These changes restrict the development of the sugar beet root system, resulting in decreased yield and reduced sugar content. The study highlights the importance of scientifically based agrotechnical and reclamation measures to preserve soil fertility and prevent productivity losses.*

Keywords: *Soil pollution, sugar beet, soil fertility, agrochemical analysis, yield losses, agricultural ecosystems*

Introduction

Soil plays an irreplaceable role in the life of humans and entire ecosystems. For agricultural ecosystems, soil serves not only as the fundamental basis for crop production but also as a critical factor in ensuring food security (Aliyev, 2015). However, in recent years, soil pollution has become one of the greatest challenges facing both ecosystems and the economy. It hinders the sustainable management of natural resources and the continued provision of ecosystem services. As a result of soil pollution, yield losses in agricultural fields and their impact on food production have become a global concern (Lehmann et al., 2020).

One of the primary causes of soil pollution is the improper or excessive use of chemical substances, including pesticides, fertilizers, industrial waste, and heavy metals, which accumulate in the soil. These substances alter the chemical structure of the soil, reducing its fertility and hindering the normal development of plants (Montanarella & Panagos, 2021). The long-term use of pesticides and fertilizers in agriculture leads to the accumulation of toxic substances in the soil and groundwater. This, in turn, reduces biological diversity within the ecosystem, decreases soil fertility, and ultimately results in economic difficulties.

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Received: 10 December 2025; Accepted: 4 April 2026; Published online: 25 April 2026

Soil pollution not only harms agriculture but also has serious impacts on local and global ecosystems, as well as human health. Crops grown on contaminated soils can enter the human food chain, leading to the accumulation of toxic substances and ultimately causing food safety issues. Contaminated soils also negatively affect local animal species and vegetation, disrupting the overall health of the ecosystem. Such disturbances in ecosystem balance can lead to long-term changes across various biological processes and threaten the sustainability of natural environments. Restoration methods for soil remediation, such as the application of organic fertilizers and natural pesticides, as well as crop rotation and the restoration of soil cover, are of particular importance. However, these approaches are effective only to a certain extent, as heavily contaminated soils require more intensive rehabilitation processes (Rodríguez-Eugenio et al., 2018).

Research on this topic explores solutions that, from both ecological and economic perspectives, support the development of modern agricultural technologies and enhance the productivity of cultivated fields. Modern technologies applied for the restoration of contaminated soils and the protection of ecosystems ensure the sustainable use of soil and the preservation of cultivated lands for future generations (Wang et al., 2021).

This study investigates the impact of soil pollution on agricultural ecosystems and identifies the main factors contributing to yield losses. Practical recommendations for addressing these issues are also proposed. Suitable management methods and ecological approaches are analyzed to ensure sustainable agricultural development, restore ecosystems, and enhance crop productivity.

Literature Review

Soil pollution occurs as a result of harmful substances entering the soil due to various human activities. Soil contamination alters the physical, chemical, and biological properties of the soil, which in turn negatively affects agricultural productivity and ecosystem functions. Recent studies have highlighted the impacts of various soil pollutants and their mechanisms:

Rashid et al. (2023) discussed the effects of pesticides and heavy metals on soil microbial diversity and nutrient uptake by plants, noting that these contaminants can significantly reduce crop growth and productivity. Similarly, Lal (2015) reported that the use of pesticides alters the chemical composition of the soil and affects ecosystem food chains.

Diacono & Montemurro (2010) demonstrated that heavy metals, such as lead and cadmium, contaminate soils, damaging soil structure and reducing agricultural yields. Montanarella & Panagos (2021) emphasized that industrial waste and persistent organic pollutants (POPs) disrupt soil microbial activity and impair the cycling of organic matter, limiting the availability of nutrients for crops.

Lehmann et al. (2020) provided a comprehensive review of how soil pollution impacts agricultural productivity, highlighting the importance of soil remediation and sustainable management practices. Luo et al. (2023) also underscored the significance of adopting sustainable agricultural approaches and modern technologies to mitigate the effects of soil contamination and improve crop yield.

Overall, these studies indicate that soil pollution is a major factor reducing agricultural productivity, disrupting ecosystem services, and posing risks to food security. They emphasize the need for scientifically based soil management, remediation techniques, and environmentally friendly agricultural practices to maintain soil fertility and ensure sustainable crop production (Brevik et al., 2015).

Materials and Methods

Yevlakh district is one of the regions in Azerbaijan that plays a significant role in agricultural production. Its favorable soil and climatic conditions provide extensive opportunities for the cultivation of various agricultural crops, particularly sugar beet. The fields of Azershakar LLC, one of the main sugar beet producers in the region, hold strategic importance both economically and agriculturally. However, in recent years, intensive agricultural activities, industrial and domestic influences, and the excessive use of mineral fertilizers and pesticides have led to soil contamination in these areas (Alloway, 2013).

The primary aim of this study was to assess the level of soil pollution in the sugar beet fields of Azershakar LLC in Yevlakh district, evaluate its effects on the physical and agrochemical properties of the soil, and scientifically investigate the relationship between these changes and yield losses. The results of this study are expected to provide a scientific basis for the efficient management of soils, the enhancement of crop productivity, and the development of environmentally sustainable agricultural practices (Luo et al., 2023).

Soil pollution in the sugar beet fields of Yevlakh district not only negatively affects the physical, chemical, and biological properties of the soil but also restricts normal plant development, reduces nutrient uptake, and consequently leads to a decline in crop yield. In contaminated soils, structural degradation, alterations in pH, and reductions in humus and essential nutrient levels pose significant risks to the sustainability of agricultural ecosystems.

Soil samples were collected from the 0–30 cm and 30–60 cm layers using a selective sampling method in accordance with national standards, taking into account the field's morphological characteristics and topography. The samples were prepared for laboratory analyses and subjected to physical, physico-chemical, and agrochemical investigations. Soil analyses were conducted using methods in accordance with international ISO standards (Kozjek et al., 2022). Crop yield indicators were determined based on production per hectare (t/ha) and analyzed in relation to the level of soil contamination.

Table 1
Physical Properties of Soil under Sugar Beet Cultivation at Azershakar LLC, Yevlakh District

Treatment	Replicate	Soil Texture (%)	Soil Moisture (%)	pH (H_2O)	Total Salinity (mg-eq/L)
I – Control	R_1	32 clay, 38 loam, 30 sand	18.5	6.8	0.12
	R_2	33 clay, 37 loam, 30 sand	18.7	6.9	0.13
	R_3	31 clay, 39 loam, 30 sand	18.4	6.8	0.12
II – Moderately Contaminated	R_1	35 clay, 40 loam, 25 sand	19.0	7.2	0.18
	R_2	34 clay, 41 loam, 25 sand	19.2	7.1	0.19
	R_3	35 clay, 39 loam, 26 sand	18.9	7.2	0.18
III – Highly Contaminated	R_1	36 clay, 42 loam, 22 sand	20.1	7.5	0.28

Treatment	Replicate	Soil Texture (%)	Soil Moisture (%)	pH (H_2O)	Total Salinity (mg-eq/L)
	R_2	35 clay, 43 loam, 22 sand	20.3	7.6	0.29
	R_3	36 clay, 41 loam, 23 sand	20.0	7.5	0.27

Table 2
Agrochemical Properties of Soil under Sugar Beet Cultivation at Azershakar LLC, Yevlakh District

Treatment	Replicate	Humus (%)	Easily Available N (mg/kg)	P (mg/kg)	K (mg/kg)	Cl^- (mg-eq/L)	SO_4^{2-} (mg-eq/L)	Ca^{2+} + Mg^{2+} (mg-eq/L)	Na^+ (mg-eq/L)
I – Control	R_1	3.2	45	22	180	5.0	8.0	14.5	2.1
	R_2	3.1	46	23	182	5.1	7.8	14.6	2.2
	R_3	3.2	45	22	181	5.0	8.1	14.4	2.1
II – Moderately Contaminated	R_1	2.8	38	20	175	7.0	12.0	16.5	4.0
	R_2	2.9	39	21	176	7.2	12.1	16.6	4.2
	R_3	2.8	38	20	175	7.1	11.9	16.4	4.1
III – Highly Contaminated	R_1	2.2	30	18	160	10.0	18.0	20.0	7.5
	R_2	2.3	31	19	162	10.2	17.8	20.2	7.6
	R_3	2.2	30	18	161	10.1	18.1	19.9	7.5

Results and Discussion

The results of the study indicate that as soil pollution increases in the sugar beet fields of Azershakar LLC inYevlakh district, significant changes occur in the physical properties of the soil (Table 1). In the control plots, the soil texture was balanced, with clay, loam, and sand fractions creating favorable conditions for the optimal development of the sugar beet root system. The optimal soil moisture and neutral pH in these plots allowed for deep root growth (Lal, 2015).

In moderately contaminated plots, an increase in the clay and loam fractions of the soil texture led to higher soil compaction and somewhat restricted water–air regime. Although root system development was impaired in these plots, the plants were still able to partially maintain their yield potential. In highly contaminated plots, soil compaction, excessive moisture accumulation, and a shift of pH towards alkalinity significantly restricted root system development. As a result, root biomass formation was reduced, leading to a decline in overall crop yield.

Agrochemical analyses demonstrated a direct relationship between soil pollution and crop yield (Table 2). In the control plots, optimal levels of humus and key macronutrients (N, P, K) supported intensive vegetative growth of sugar beet and high root productivity. In these plots, the average yield ranged from 50 to 55 t/ha, and the average root biomass was notably high.

In moderately contaminated plots, the reduction in humus and macronutrients weakened the plants' ability to uptake nutrients. As a result, the yield decreased to 42–45 t/ha, and root biomass formation was reduced; however, the sugar content remained relatively stable. This indicates that during the early stages of soil contamination, yield losses occur, but the plants still exhibit compensatory mechanisms.

In highly contaminated plots, a sharp decline in humus reserves, deficiencies in nitrogen, phosphorus, and potassium, and the excessive accumulation of sodium disrupted the agrochemical balance of the soil. Under these conditions, the sugar beet root system was poorly developed, vegetative biomass decreased, and consequently, the yield dropped to 30–35 t/ha. At the same time, the sugar content also declined, resulting in significant economic losses.

The study results indicate that soil pollution affects not only root productivity but also the technological quality of sugar beet, particularly the sugar content. In the control plots, sugar content ranged from 16–17%, in moderately contaminated plots it was 14–15%, and in highly contaminated plots it decreased to 12–13%. This decline is attributed to increased soil alkalinity and reduced nutrient uptake by the plants.

The parallel decline in sugar content and yield indicates that soil pollution causes losses in both the quantity and quality of sugar beet production. This situation can be considered a significant risk factor for Azershakar LLC in terms of raw material supply and economic efficiency.

The obtained results are consistent with previous studies and confirm that soil pollution leads to a decline in productivity within agroecosystems. In particular, sodium accumulation in the soil and a reduction in humus content were identified as the main factors weakening sugar beet root development. The deterioration of soil structure leads to water stagnation under irrigation conditions, which increases the risk of root rot (FAO & ITPS, 2015).

Thus, the studies conducted in the sugar beet fields of Azershakar LLC in the Yevlakh district demonstrate that soil pollution directly and negatively affects sugar beet yield and sugar content by altering the physical and agrochemical properties of the soil. Measures aimed at reducing soil pollution and restoring soil fertility are essential to prevent yield losses (Diacono & Montemurro, 2010).

Conclusions

The comprehensive investigation conducted in the sugar beet cultivation fields of Azershakar LLC in the Yevlakh district unequivocally demonstrates that soil contamination exerts a profound and multifaceted influence on both the physico-chemical properties of the soil and the agronomic performance of sugar beet. The empirical data indicate that alterations in soil texture, humus content, macronutrient availability, and ionic composition (notably sodium accumulation) collectively disrupt the biogeochemical equilibrium, thereby constraining root morphogenesis, nutrient uptake efficiency, and overall vegetative and generative growth.

The principal conclusions derived from this study are summarized as follows:

1. Soil contamination precipitates a significant reorganization of soil mechanical composition, manifesting in increased bulk density and compromised porosity, which directly impedes water–air regimes essential for optimal root development and metabolic activity.
2. Control plots, characterized by balanced soil texture, neutral pH, sufficient humus content, and adequate macronutrient supply (N, P, K), facilitated intensive vegetative growth, maximal root biomass accumulation, and elevated sugar yield, serving as a benchmark for assessing contamination-induced deviations.
3. Moderately contaminated soils exhibited diminished humus reserves and reduced macronutrient bioavailability, resulting in attenuated nutrient uptake efficiency. This led to a moderate decline in

yield (42–45 t/ha) while sugar content remained relatively stable (14–15%), suggesting the activation of intrinsic compensatory physiological mechanisms in sugar beet.

4. Highly contaminated plots were marked by severe humus depletion, critical deficiencies in N, P, and K, excessive Na^+ accumulation, and pH shifts toward alkalinity, which collectively impaired root system architecture and vegetative development, culminating in substantial reductions in yield (30–35 t/ha) and sugar content (12–13%).
5. The parallel diminution of quantitative and qualitative productivity parameters underscores the dual adverse impact of soil contamination on both yield potential and technological quality, thereby representing a tangible threat to the raw material security and economic efficiency of Azershakar LLC**.**
6. These findings corroborate and extend previous studies, confirming that soil contamination constitutes a pivotal limiting factor in the sustainability of agroecosystems, particularly in intensive sugar beet production zones.

Recommendations

In light of the above findings, the following scientifically grounded, agronomically and environmentally oriented interventions are proposed:

1. Implementation of integrated soil reclamation strategies aimed at mitigating sodium accumulation and restoring structural stability, including chemical amelioration (e.g., gypsum application), subsoiling, and other deep tillage techniques to enhance porosity and water–air exchange.
2. Augmentation of soil organic matter through systematic incorporation of organic fertilizers, green manure crops, and crop residues to restore biogeochemical cycling, stimulate microbial activity, and improve nutrient retention.
3. Optimization of fertilization regimes, informed by rigorous and periodic agrochemical soil analyses, to correct macro- and micronutrient deficiencies and enhance nutrient use efficiency.
4. Rationalization of irrigation and drainage management to prevent waterlogging, secondary salinization, and further degradation of soil physical properties, particularly in areas with high clay content and compaction.
5. Establishment of a continuous soil monitoring and assessment framework to evaluate contamination levels, nutrient dynamics, and soil health indicators, ensuring sustainable, economically efficient, and ecologically sound sugar beet production.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 90–94
DOI: https://doi.org/10.36719/2707-1146/65/90-94

Economic Performance Indicators of Promising Kiwi Varieties Cultivated in the Lankaran Region

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Abstract. *This article extensively investigates the main agronomic and biological characteristics of promising kiwi cultivars grown in the southern subtropical zone of Azerbaijan, particularly in the Lankaran-Astara region.The aim of the study was to conduct a comparative evaluation of the productivity potential, fruit quality, ecological adaptability, and economic efficiency of different kiwi cultivars. The research focused on four cultivars of Actinidia deliciosa: Hayward, Bruno, Shahla, and Abbott. The research was conducted in specialized plantations located in the Lankaran-Astara region and included long-term phenological observations, biometric measurements, and laboratory analyses. Phenological stages (flowering, fruit set, and ripening), plant biometric parameters (shoot length, leaf area, fruit weight), as well as productivity and fruit quality indicators (sugar content, acidity, dry matter content were studied. The obtained results were statistically analyzed, and the economic efficiency of the cultivars was evaluated based on production costs and market revenues. The results showed that the Hayward and Shahla cultivars had higher productivity, larger fruit weight, better market appearance, and superior taste qualities. The Bruno and Abbott cultivars, while satisfactory in terms of certain agro-biological characteristics, perform less well than in overall economic efficiency. Overall, the Hayward and Shahla cultivars are considered more promising for the Lankaran-Astara region. The obtained data are of significant scientific and practical importance for the expansion of kiwi cultivation in the region, the selection of optimal cultivars, and the development of export-oriented production.*

Keywords: *kiwi, Actinidia deliciosa, cultivar, yield, economic indicators, subtropical zone*

Introduction

Kiwi (*Actinidia deliciosa)* is a subtropical fruit crop with high nutritional value, rich biochemical composition, and wide utilization potential, and it is among the rapidly expanding fruit species worldwide (Huang, 2016; Testolin et al., 2019). Kiwi fruit is particularly characterized by its richness in vitamin C, organic acids, mineral elements, and bioactive compounds (Korkmaz et al., 2023). These characteristics make it a valuable raw material for both fresh consumption and the processing industry.

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Received: 28 December 2025; Accepted: 14 March 2026; Published online: 25 April 2026

The fruit's unique chemical composition, along with its diverse medicinal and organoleptic properties, has contributed to the widespread cultivation of this valuable subtropical crop (Liu et al., 2016). Kiwi fruits are rich in vitamins C, A1, B1, B2 and P, as well as mineral salts, aldehydic compounds, and phenolic compounds (Korkmaz et al., 2023). All of these contribute to increased resistance to infectious diseases in the human body, support the maintenance of hemoglobin levels in the blood, and have a positive effect on cell regeneration and muscle strengthening (Testolin et al., 2019).

One of the main bioecological characteristics of kiwi plants is their relatively high frost tolerance (down to -15 °C), with some species even capable of withstanding temperatures of -25 to -30 °C (Richardson et al., 2018). The plant has a well-developed root system concentrated in the upper soil layer (25–30 cm), and its resistance to diseases and pests enables its cultivation alongside other subtropical crops (Peterson & Willett, 2000).

The kiwi vine is also widely used as an ornamental plant in recreational areas, along water bodies, and in parks (Müller et al., 2015). In addition, pruned kiwi shoots are utilized for weaving baskets and producing various souvenirs.

In recent decades, the role of agriculture, particularly fruit production, has increased in the development of Azerbaijan's non-oil sector. The Lankaran-Astara subtropical zone, with its unique humid climate, mild winters, and fertile soils, is considered a highly suitable region for kiwi cultivation (Mammadov, 2018). The area under kiwi orchards in this region has been expanding year by year. However, the proper selection of cultivars remains a key factor in ensuring high productivity efficiency.

In this context, the scientific assessment of the ecological adaptability, productivity, and fruit quality traits of promising kiwi cultivars based on sound scientific principles is of significant theoretical and practical importance (Liu et al., 2016). The present study provides a comprehensive analysis of the main agronomic characteristics of the widely cultivated Hayward, Bruno, Shahla, and Abbott cultivars in the Lankaran-Astara region (Mammadov, 2018).

Methods

The main agronomic characteristics of kiwi plants play an important role in evaluating their suitability for production and their economic efficiency. These indicators reflect the crop's yield potential, fruit quality attributes, and profitability in relation to cultivation costs (Ferguson & Huang, 2007).

In kiwi cultivation, yield is determined by the amount of produce obtained per plant and per hectare. Under subtropical conditions and with proper agronomic management, an average yield of 30–50 kg per plant and 15–25 tons per hectare can be achieved (Eynard et al., 1992).

Results and Discussion

The average fruit weight varies between 70 and 120 g depending on the cultivar. Large and uniformly shaped fruits are considered more suitable for the market. Fruit quality is characterized by dry matter, sugar, organic acids, and vitamin C content. Dry matter ranges from 12–18 %, while sugar content varies between 8–12%. Kiwi fruits contain more than 160 mg% vitamin C and over 170mg% vitamin A, as well as a high level of mineral salts (Ca, Mg, P, Fe, K, etc.) (Korkmaz et al., 2023).

Although kiwi fruits are not particularly attractive in external appearance, the emerald-green flesh is aromatic and characterized by a sweet-sour taste with a flavor profile reminiscent of feijoa, strawberry, blackberry, pineapple, watermelon, and banana. Actinidia fruits play an crucial role in regulating dietary balance. They enhance the body's resistance to diseases, promote tissue regeneration, and strengthen muscles (Testolin et al., 2019).

The results of phenological observations of the studied kiwi cultivars during the research years are presented in Table 1 below.

Table 1
Phenological observations of the studied kiwi cultivars

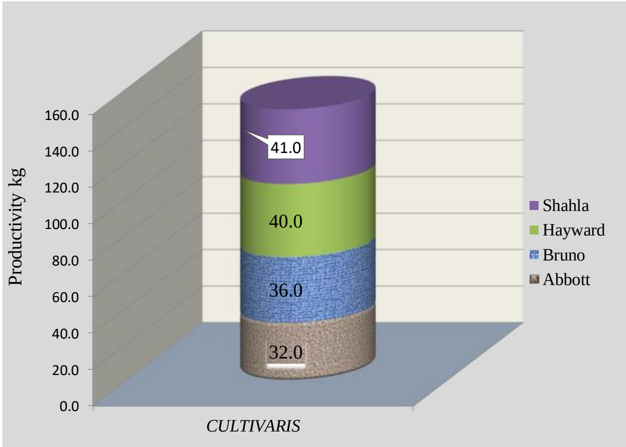
Kiwi cultivars	Age of the plant	Growth stage	Bud swelling	Bud burst	Shoot formation	Leaf development	Budding	Flowering	Fruit formation	Fruit ripening
Hayward	10	Initial stage	25.III	27.III	07. IV	10. IV	10. IV	16. V	20. V	12.XI
		Large-scale	26.III	02. IV	9. IV	15. IV	15. IV	19. V	26. V	18.XI
Shahla	10	Initial stage	22.III	25.III	02. IV	09. IV	09. IV	18. V	19. V	15.XI
		Large-scale	24.III	27.III	04. IV	14. IV	14. IV	25. V	21. V	21.XI
Bruno	10	Initial stage	25.III	02. IV	05. IV	08. IV	09. IV	18. V	24. V	14.XI
		Large-scale	27.III	03. IV	09. IV	13. IV	15. IV	25. V	29. V	22.XI
Abbott	10	Initial stage	23.III	04. IV	10. IV	11. IV	11. IV	15.V	18. V	5.XI
		Large-scale	25.III	06. IV	12. IV	17. IV	17. IV	22.V	21. V	10.XI

Kiwi cultivars begin bearing fruit in the third to fourth year after planting, while full productivity is typically observed in the sixth to eighth years. The vegetation period averages 210–240 days (Yuan et al., 2023).

Kiwi fruits have good storage and transportability and can be stored under refrigerated conditions for 4–6 months without significant loss of quality, which increases their export potential. Compared with other subtropical crops, this is a relatively high indicator (Wei et al., 2025).

In terms of economic indicators, high yield and long storage life ensure the profitability of kiwi production. The income obtained from one hectare of kiwi orchard can be higher compared to other subtropical fruit crops.

During the research period, the yield characteristics of promising kiwi cultivars were studied comparatively. It was found that there are significant differences among cultivars in terms of yield per plant and per hectare.



Average yield per plant in kiwifruit cultivaris

Figure 1
Comparative yield performance and stability of kiwifruit cultivars
(Shahla, Hayward, Bruno, Abbott)

As shown in the diagram, the Shahla cultivar demonstrated the most stable and consistently high yield over the study years. On average, it produced 36–41 kg per plant and 19–21 tons per hectare. The Hayward cultivar showed relatively high productivity; however, inter-annual variability was observed (36–40 kg per plant). The Bruno cultivar exhibited comparatively lower yield, also with noticeable year-to-year fluctuations (34–36 kg per plant). Although the Abbott cultivar is early-maturing, it lagged behind the other cultivars in terms of yield (28–32 kg per plant).

These indicators demonstrate that the Shahla and Hayward cultivars are more promising for the Lankaran-Astara region. Fruit quality parameters, including average fruit weight, dry matter content, sugar content, and taste characteristics, were studied.The analyses showed that the average fruit weight of the Shahla cultivar ranged between 100–120 g. In the Hayward cultivar, it ranged from 90–110 g. In the Bruno cultivar, this parameter was 80-95, while in the Abbott cultivar it was 70–85 g. (Hasanov & Aliyev, 2012).

The dry matter content was 16–17% in Shahla, 14–16% in Hayward, 13–15% in Bruno, and 12–14% in Abbott. In terms of sugar content, the Bruno cultivar showed relatively higher values, which is crucial factor enhancing both market and taste quality of the fruit.

The market value of promising kiwi cultivars is mainly determined by fruit size, external appearance, transportability, and storage capacity. The Hayward and Shahla cultivars are distinguished by their large fruit size and their ability to maintain quality during long-term storage and transport. These features make them more attractive as export-oriented products.

Economic calculations showed that the cultivation of Shahla and Hayward cultivars provides higher profitability compared to the other cultivars. The net income per hectare was higher than that of the Bruno and Abbott cultivars. In this regard, the Hayward cultivar was evaluated as the most economically efficient. At the same time, the sustainability and profitability of kiwi production are closely related to risk management and agricultural insurance mechanisms, which play an important role in protecting farmers against climatic and market uncertainties (Famiani et al., 2012).

Conclusion

Based on comprehensive comparative agronomic evaluation of promising cultivars, it was determined that under the soil and climatic conditions of the Lankaran-Astara subtropical region, the Hayward and Shahla cultivars are superior in terms of yield, fruit quality, and economic efficiency. The Bruno cultivar is notable for its productivity but is inferior to Hayward in fruit quality and storage capacity. The Abbott cultivar has the advantage of early fruiting; however, it is relatively weaker in overall yield and economic indicators.

The obtained results are of significant scientific and practical importance for the proper selection of kiwi cultivars in production, the expansion of kiwi cultivation, and the development of horticulture in subtropical regions. Thus, the conducted research enabled scientifically based evaluation of the agronomic performance of promising kiwi cultivars and the selection of optimal cultivars for production.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 95–101
DOI: https://doi.org/10.36719/2707-1146/65/95-101

Anthelmintic Activity of Chitosan and its Derivatives

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Abstract. *Chitosan is a biodegradable and biocompatible derivative of chitin which is the second most abundant biopolymer after cellulose. It is mainly found in the exoskeletons of crustaceans and mollusks, as well as in fungi and insect cuticles. Due to its cationic nature and biological safety, chitosan is of a great interest for biomedical and veterinary applications. Numerous studies have demonstrated that chitosan and its derivatives possess anthelmintic, antimicrobial, and antifungal properties. When applied alone, chitosan has been reported to reduce the number of animal and plant helminths, indicating its direct and indirect suppressive effects. In addition, chitosan is widely used as a nano-coating and delivery agent to improve the oral bioavailability and therapeutic efficacy of conventional anthelmintic drugs. In animal studies, most applications achieved the desired outcomes, including reductions in helminth burden or egg counts; however, depending on the concentration and formulation, some cases reported mild host-related side effects or limited toxicity against helminth. Overall, chitosan represents a promising and versatile tool for sustainable helminth management, although its efficacy and safety are strongly dose-dependent.*

Keywords: *chitosan, nano-derivatives, anthelminthic, nematode, cestode, trematode*

Introduction

Chitin is considered the second most abundant polysaccharide on Earth and it appears in Nature as ordered macrofibrils in the exoskeleton of mollusks and crustaceans, as well as in fungi and insect cuticles (Jiménez-Gómez & Cecilia, 2020). Chitosan is produced from chitin mainly through demineralization, deproteination, and deacetylation. Few studies proved presence of decolorization as a minor step (Thambiliyagodage et al., 2023). To produce chitosan natural or synthetic chitin is used as a raw material. Chitosan has attracted considerable scientific interest in recent years because of its several properties. Chitosan has bioactivity because of the primary amino groups in the chitosan's main chain. Therefore, the chitosan is widely used in the biomedical fields such as drug and gene delivery, in the industrial fields such as water treatment (for example, harmful algae control), or against bacterial, fungal and other pathogen invasions (Choi et al., 2016). Chitosan has several biologically convenient features, such as nontoxicity, biocompatibility, biodegradability, bioactivity etc. The synthesis of chitosan with inorganic nanoparticles has used for controlled drug delivery (Li et al., 2018; Parhi, 2020).
Chitin can be degraded by internal enzymes (lysozymes and chitosanases) and are subsequently absorbed by the body. Despite of these features, chitin has not been extensively utilized in the clinic due to its low solubility and poorly learned mechanical properties (Li et al., 2018). Positive charged amino groups of chitosan can interact with various negatively charged components.

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Received: 8 January 2026; Accepted: 22 March 2026; Published online: 25 April 2026

And some of these negatively charged components are found on the microbial membrane, creating antimicrobial properties of chitosan which is of great interest nowadays (Ke et al., 2021; Chandrasekaran et al., 2020). Additionally, there are 2 types of chitosan: low-molecular weight chitosan (LWC) and high-molecular weight of chitosan (HWC). Usually, HMW can't penetrate into cell, and its antimicrobial activity is due it changes cell permeability and control nutrient uptake and intake (Hu et al., 2009; Kong et al., 2010).

However, LWC can intervene intracellular activity, change RNA, protein synthesis to provide antimicrobial properties which makes it highly toxic for different pathogens such as bacteria, fungi, even helmiths (Rabea et al., 2003). Not only chitosan itself, but its derivatives, especially chitosan nanoparticles are of great interest and increase known potential of chitosan into another level. Nanoparticles provide more reactive surface to chitosan which increases its antipathogenic ability several times (Chandrasekaran et al., 2020; Kravanja et al., 2019). Antipathogenic effectivity of chitosan and its nano-derivatives are dependent on several factors like molecular weight, pH, temperature, type of pathogen and so on (Chandrasekaran et al., 2020; Kong et al., 2010; Kravanja et al., 2019; Li & Zhuang, 2020).

Our article examines the antihelmintic property of chitosan and its nano-derivatives. Particular attention is given to their underlying mechanisms of action and the parameters affecting their biological effectivity of chitosan and its derivatives against animal helminths. Furthermore, recent advances and new studies in this area are reviewed to outline current progress and future research directions.

Antipathogenic nature of chitosan

Mode of action

Previous studies have demonstrated significant antipathogenic activity of chitosan; however, the underlying molecular mechanisms remain largely unclear. There are several hypotheses. First idea is binding of chitosan and its derivatives to bacterial DNA which leads to inhibition of mRNA synthesis. Generally, it is known that chitosan has an ability to bind DNA or RNA because of its positively charged amino groups. This ability of chitosan and its derivatives also used in gene and drug delivery. And some scientists suggest that LWC can penetrate into pathogen and interrupt synthesis of vital proteins (Cao et al., 2019; Li et al., 2018). Another and mostly accepted idea are disruption of cell wall of pathogen because of polycationic nature of chitosan (Divya et al., 2017).

The presence of amine groups in each glucosamine monomer allows chitosan to interact with negatively charged surface components of many microorganisms, including bacteria, fungi etc. This causes alterations to the cell surface components, leading to leakage of intracellular substances that results in cell death (Divya et al., 2017; Ganan et al., 2009; Raafat et al., 2008; Ardila et al., 2017). Researches show that lipopolysaccharide in Gram-negative bacteria and teichoic acid in Gram-positive bacteria play a major role in binding of chitosan (Raafat et al., 2008; Ardila et al., 2017). Other idea is disruption of Electron Transport Chain in mitochondria which has not proven yet (Chandrasekaran et al, 2020).

Records of anthelmintic activity of chitosan in animals

There are a lot of studies describes study on anthelmintic activity of chitosan and its nano-derivatives against animal nematodes. In Egypt, some of the scientists had done research on 240 domestic pigeons that 97% of them had single or mixed gastrointestinal parasites. They were determined 8 species of helminths and *Ascaridia columbae* was most predominant gut parasite between helminths. Therefore, it was subjected to *in vitro* and *in vivo* treatment with chitosan nanoparticles. Their results demonstrated that chitosan nanoparticles reduced the severity of clinical signs, prevented mortality, and induced repair of intestinal tissues. However, they revealed that chitosan nanoparticles caused shrinkage in the worm moth part and induced destructive damage to bird's body (Salem et al., 2022).

Another application of chitosan against intestinal nematode was done by Egyptian scientists. *Syphacia muris* mainly infects laboratory rats and had adverse effect on their immune systems. Different biochemical, and histological analysis showed that chitosan treatment reduced the worm number in infected rats. Overall, their findings proved an anthelmintic effect of chitosan against *Syphacia muris* (Mostafa et al., 2024).

Chitosan is a natural, biodegradable polymer with strong potential for pharmaceutical use mainly due to its biocompatibility and low toxicity (Yadav et al., 2023; Thambiliyagodage et al., 2023; Jimenez-Gomez & Cecilia, 2020). Therefore, chitosan and its nano-derivatives are widely used as coating and delivery agents for anthelmintic drugs to enhance their transport to the host and improve efficacy against nematodes and other helminths. Priotti et al. (2017) used chitosan to coat albendazole microcrystal formulations, drug against internal nematodes to increase its solubility ability. They had used chitosan, cellulose derivatives, and poloxamer as a coating agent, but chitosan had the best results among them according to the ANOVA analysis. In vitro evaluation of anthelmintic activity of this complex against adult *Trichinella spiralis* also proved that the S10A formulation (albendazole + chitosan complex) was the most effective, and it was therefore selected for the next in vivo therapeutic studies (Priotti et al., 2017).

Another study evaluated *in vitro* and *in vivo* anthelmintic effect and toxicity of chitosan encapsulated bromelain in goats. Bromelain is obtained from pineapple and have anthelmintic activities. But its anthelmintic activity is decreased by the low pH in stomach of ruminants. Chitosan encapsulated bromelain solution was used against *Haemonchus contortus* nematode both *in vivo* and *in vitro*. They had determined that chitosan encapsulated bromelain showed a higher *in vivo* fecal egg count reduction in compared to the plain bromelain *in vivo* studies (Wasso et al., 2020). For the further investigation, 20 healthy male goats naturally infected with gastrointestinal nematodes (GIN) and coccidia, and they used nanoencapsulated bromelain for 60 days. Fecal egg counts (FEC) and fecal oocyst counts (FOC) was decreased at 7^{th} day of experiments. At 28 days of treatment, The FEC and FOC were zero in goats treated with nanoencapsulated bromelain and they hadn't observed any lesions or damage in the organs of goats (Ahmota et al., 2023).

Trichinella spiralis causes trichinellosis disease in humans and Eid et al. (2020) used chitosan coated nanostructured lipid carriers to carry albendazole into mice via oral administration. Albendazole (ABZ) is a drug against intestinal worms and is used in treatment of trichinellosis. However, it has limited bioavailability. To enhance the dissolution rate and oral bioavailability of ABZ, they used albendazole suspension, coated and uncoated nanostructured lipid carriers. They observed reduced larval count by 62.9, 99.6 and 89.5%, respectively (Eid et al., 2020).

Another study learned the effect of chitosan particles on human intestinal cestode, *Hymenolepis nana* to see if it kills this cestode and increases host's immunity against *H. nana*. They have studied worm burden, egg output, histopathology, oxidative stress markers and other parameters to address the aim correctly. Their results showed that treatment significantly reduced adult worms and egg counts. It also improved tissue damage and oxidative stress. Chitosan downregulated pro-inflammatory and Th1-related markers (iNOS, IFN-α, IFN-γ, TNF-α, IL-9) while upregulating MUC2, IL-4, and SCF (intestinal cytokine genes) expression, with normalization of goblet and mast cell numbers (Abdel-Latif et al., 2017).

Firouzeh et al. (2021) evaluated chitosan nanoparticles against hydatid cysts caused by *Echinococcus granulosus*. This cestode causes cystic echinococcosis in human, and their purpose was to find a special chemical that has an ability to kill cysts of *E. granulosus* during operations which is called as scolicidal agent. They used different concentrations (125–1000 µg/ml) and tested at various exposure times (10–180 min) *in vitro*. The nanoparticles showed notable scolicidal effects compared with the control, with activity increasing in a dose- and time-dependent manner. The highest killing effect was observed at 1000 µg/ml after 180 minutes of exposure. Importantly, no significant hemolytic activity was detected during *in vitro* chitosan nanoparticle application (Firouzeh et al., 2021).

Another study learned the effect of chitosan–curcumin nanoparticles on *E. granulosus*. 0.25, 0.05, 1, 2, and 4 mg/mL concentrations of nanoparticles were used and the highest mortality (68%) was observed at 4 mg/mL. They determined that nanoparticles also decreased protoscolex size (Napooni et al., 2019). Effect of albendazole–chitosan microspheres was evaluated on another species of same genus (Abulaihaiti et al. 2015). They assessed pharmacological and antiparasitic efficacy of the substance against metacestodes of *Echinococcus multilocularis* in experimentally infected mice. Oral treatment for 12 weeks exhibited that effectively reduced parasite tissue weight and strongly suppressed metacestode growth. Histological essays revealed severe structural damage to cyst layers and a shift toward a protective Th1 immune response.

Egypt scientists examined 453 *Oreochromis niloticus* and showed a high prevalence (40.8%) of fish-borne zoonotic trematodes, mainly *Clinostomum* spp. and *Prohemistomum vivax*. Chitosan, silver, and selenium nanoparticles were synthesized and tested *in vitro* against these trematodes. Chitosan nanoparticles exhibited the highest antiparasitic efficacy, producing the lowest LC50 and LC90 values for both parasite species and they acted faster than silver and selenium nanoparticles. Ultrastructural analysis by SEM confirmed that chitosan caused the most severe tegumental destruction, including ridge loss, shrinkage, and bleb formation. These results clearly indicate that chitosan nanoparticles are the most effective agent against trematodes (Mahdy et al., 2024).

Biomphalaria alexandrina is an intermediate host for the trematode, *Schistosoma mansoni*. This trematode’s eggs trigger chronic inflammation and liver fibrosis in human, and lead to severe complications. It also affects millions of people in endemic areas, causing long-term illness and economic burden. El-Menyawy et al. (2021) used three treatment methods to prevent this cycle: hymoquinone, chitosan nanoparticles and hymoquinone loaded with chitosan nanoparticles (El-Menyawy et al., 2021). They found that hymoquinone loaded with chitosan nanoparticles were the most effective against trematode without giving damage to snail itself. There is another study were scientists used *Orobanche aegyptiaca* (Egyptian broomrape) + chitosan nanocomposite to fight against *Biomphalaria alexandrina* itself and had successful results in disruption of cycle (Abdel-Khalek et al., 2025).

Taken together, these findings indicate that further experimental studies are required to validate the efficacy and safety of chitosan-based formulations. Nevertheless, the current evidence consistently highlights chitosan as a highly promising molecule with significant potential for anthelmintic applications.

We study the pathomorphological changes caused by the accumulation and bioaccumulation of a number of biologically active and newly synthesized substances, as well as some nanoparticles, in living organisms at the ultrastructural level (Ahmadov et al., 2018; Hajiyeva et al., 2019; Hajiyeva et al., 2023; Nasirov et al., 2024). Despite the fact that poultry and fish products currently play a major role in satisfying the population's demand for meat, helminths that seriously affect the quality of their meat are still found (Rzayev et al., 2021; Rzayev 2021a,b; Seyidli et al., 2022). Therefore, there is a need to study the anthelmintic properties of chitosan against fish and bird parasites.

Conclusion

Chitosan and its derivatives are safe, biodegradable, and versatile agents with anthelmintic, antimicrobial, and antifungal properties. They can reduce helminth burden both directly and indirectly, and serve as effective nano-coating carriers for anthelmintic drugs. While most animal studies report positive outcomes, their efficacy and safety are dose- and formulation-dependent, highlighting the need for optimized application strategies in sustainable nematode management. Its large-scale use is still limited by low solubility, variable properties, production challenges, and incomplete understanding of its mechanisms. Further research in these areas will be essential to fully move chitosan from laboratory studies to practical applications.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 102–107
DOI: https://doi.org/10.36719/2707-1146/65/102-107

Click Beetles (Elateridae) Found in Eggplant Plantings in Azerbaijan

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Abstract. *The increase in the demand of the population of Azerbaijan for vegetable products has made it necessary to expand the cultivation areas of these plants. Therefore, along with other vegetable crops, various measures are being implemented in the country to increase eggplant plantings as well. In order to obtain high yield from eggplant fields, carrying out control measures against pests, diseases and weeds is of great importance. The conducted studies have shown that in eggplant cultivated fields of farmer farms engaged in vegetable growing in the republic where no control against harmful organisms is carried out, productivity decreases by approximately 55–60% every year. This situation negatively affects the economic condition of farmer farms. As a result of the research carried out in eggplant plantings it has been determined that the role of pests in the decrease of productivity is very important. In the Ganja–Gazakh region the species damaging eggplant fields were accurately identified for the first time. The studies have shown that 13 pest species belonging to four orders are distributed in these fields. Six species of them belong to the click beetle family and among this group one of the species causing the greatest damage to the crop is considered to be the field click beetle — Agriotes sputator L.*

Keywords: *eggplant, agrocenosis, Elateridae, Coleoptera, Agriotes sputator L.*

Introduction

Eggplant (Solanum melongena L.) is one of the ten most widely cultivated and important vegetable crops in the world. This plant is grown on more than 2 million hectares of land and in total approximately 33 million tons of production are obtained. China holds the leading position in eggplant production in the world and more than half of the global cultivation areas fall to its share India ranks second by producing approximately one quarter of the total world production. In addition, Indonesia, Egypt, Turkey, Iraq and the Philippines are also among the main eggplant producing countries. The Asian continent accounts for approximately 94% of the world's eggplant cultivation areas and 92% of the total production (FAO, 2007).

Eggplant can adapt well to conditions of high temperature and abundant rainfall and is considered one of the rare vegetable crops that give high yield in warm, humid climates (Hanson et al., 2006).

The composition of this plant is rich in nutrients; it contains dietary fiber, folic acid, ascorbic acid, vitamins K and B6, as well as minerals such as potassium, iron, magnesium, manganese, phosphorus and copper (USDA, 2009).

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Received: 18 December 2025; Accepted: 13 March 2026; Published online: 25 April 2026

The nutritional value of eggplant plays an important role especially during periods when other vegetables are scarce and in the nutrition of low-income populations. In tropical regions, eggplant production is seriously affected by various insect and mite pests. Among the main pests are the eggplant Colorado beetle, whiteflies, thrips, aphids, click beetles (wireworms) (Nikoukar & Rashed, 2022), stem borers and red spider mites (Rashed & van Herk, 2024). In order to protect the crop from these pests, farmers often make extensive use of chemical pesticides. For example, in Bangladesh some farmers carry out approximately 180 sprayings during the growing season (Rahman et al., 2018).

Excessive application of pesticides negatively affects both the environment and human health and leads to an increase in production costs. According to calculations carried out in the Philippines, compared with cabbage (49%) and tomato (31%), the share of pesticide costs in the total material costs in eggplant cultivation is approximately 55%. In Bangladesh this indicator varies between 40–50% (Rahman et al., 2018). Because of the high price of pesticides, many farmers prefer to abandon eggplant cultivation. This guideline provides eggplant growers and agricultural advisers with detailed information about the main insect and mite pests found on eggplant plants, as well as their management methods. The simple and low-cost integrated pest management (IPM) methods explained here make it possible to carry out effective and sustainable control and can help eggplant producers reduce their dependence on chemical pesticides. An IPM strategy for the management of eggplant pests was developed, tested and successfully implemented in the South Asia region by AVRDC – The World Vegetable Center during 2000–2005 (Alam et al., 2003; Alam et al., 2006).

Materials and Methods

During the research carried out in eggplant plantings in the Ganja–Gazakh region, the method proposed by I. Y. Polyakov (1958) was used during the vegetation period of the plant. Route observations were carried out in the farms of the Samukh, Goranboy, Shamkir and Tovuz districts where vegetable growing, including eggplant plantings, are conducted. Observations and soil sampling were conducted during 2024–2025 to determine the vertical distribution of click beetle larvae. Soil samples were taken at four depths (0–5, 6–15, 16–25, 26–35 cm), and adult beetles were monitored in the fields. Specimens were identified in the laboratory using standard taxonomic keys. Seasonal dynamics and soil-layer distribution of larvae were analyzed to support effective pest management.

Results

The composition of eggplant is rich in various vitamins (Jumshudov et al., 2015). The use of pheromone traps in the fight against eggplant moth is one of the widely applied methods. In the Republic of Belarus, the tomato moth is considered one of the dangerous pests. The main plants fed on by this pest are species belonging to the nightshade family and it damages all aboveground organs of the eggplant plant (Romanovich & Krishtofik, 2011).

In natural conditions the bracon parasitoid (Habrobracon brevicornis) can parasitize medium and large aged larvae of the cotton bollworm up to approximately 30%. Taking into account such beneficial effect of this entomophage, the bracon parasitoid is used in biological control measures against the cotton bollworm (Chernikalova, 2011). Species belonging to the order Coleoptera have also been studied by various researchers (Mammadov, 2008; Agayev, 2004).

Discussion

Information about the damage caused by these pests in eggplant fields is not sufficiently extensive. The formation of various farmer farms in our country has led to an increase in eggplant cultivation areas. For this reason, clarification of the composition of the harmful fauna for farms has been one of the main objectives of the conducted research.

During the studies carried out in 2024–2025, 6 species belonging to this family were collected from stationary eggplant fields: Agriotes gurdistanus Fald., Selatosomus latus saginatus Men., Agriotes obscurus L., Athous hirtus Hbst., Athous haemorrhoidalis F. and Agriotes sputator L. The main pest of the eggplant plant – Field click beetle (Agriotes sputator L.). During the research, since it was determined that the representative of this beetle order is a first-degree pest for eggplant plantings, its bioecological characteristics were studied in more detail. In our country the distribution of this species in all districts was noted in the data of B. I. Agayev (2004).

Click beetles (family Elateridae) belong to the order Coleoptera. It is considered necessary to determine the species composition of pests in eggplant fields, clarify the main species and conduct environmentally safe and economically efficient scientific studies against them. The studies have shown that various genera of click beetles are distributed in Azerbaijan.

During our observations this species was detected in almost all stationary eggplant fields. It was especially encountered more densely in the cultivated fields of the Shamkir district. It was also frequently observed in the grain fields near it. Taking into account the wide distribution of this species and the significant damage it causes, further studies on its bioecological characteristics are essential, as wireworms (larvae of click beetles) have been shown to be difficult to control and to impact crop health without integrated pest management approaches (Nikoukar & Rashed, 2022; Pagani et al., 2023; Gümüş Askar et al., 2023) (Fig.1).

Figure 1
Wireworms

Literature data and observations carried out in stationary fields have shown that the larvae are located in different layers of the soil and at different depths. For this reason, in 2024 soil samples were taken at different depths in the eggplant planting field of the Samukh district and it was determined that the larvae move vertically within the soil depending on the season.

The results of the research are presented in Table 2. Observations carried out in the Samukh district show that the vertical location of the larvae in soil layers shows significant changes depending on the season. It can be seen from Table 2 that in different seasons of the year the distribution of larvae in the soil undergoes sharp variations according to depths.

Table 2
Vertical displacement of larvae in soil layers depending on the season

Excavation place and date	Number of excavations	Number of larvae		Distribution by depths (in numbers), t, °C			
				up to 5 cm	6–15 cm	16–25 cm	26–35 cm
Samukh: 26.04.24	13	46	T^0	19,1 ± 2,1 17,8^0	24,2 ± 1,44 17,2^0	3,3 ± 0,33 17,1^0	0 17^0
21.05.24	17	55	T^0	7,2 ± 1,2 24,1^o	20,4 ± 2,04 23,7^0	27,1 ± 1,11 23,5^0	1,1 ± 0,1 22,6^0
18.07.24	12	49	T^0	5,5 ± 0,15 25,7^0	21,3 ± 0,33 25,0^0	22,5 ± 0,25 24,5^0	1,2 ± 0,12 23,6^0
19.08.24	13	47	T^0	6,8 ± 1,16 26,8^0	18,4 ± 2,4 26,1^1	20,4 ± 0,28 25,2	3,3 ± 0,31 24,3^0
03.10.24	15	79	T^0	11,5 ± 0,25 19,9^0	38,2 ± 4,12 20,8^0	25,5 ± 2,5 21,6^0	5,1 ± 0,11 21,9^0
20.11.24	15	71	T^0	5,1 ± 0,01 12^0	37,3 ± 3,31 13,2^o	22,4 ± 2,61 14,4^0	7,3 ± 1,1 14,9^0

Thus, observations show that the amount of larvae of the field click beetle shows significant variability according to the season. The number of larvae at a depth of 5 cm in the soil is lowest in November, July and August, and highest in April and October. At a depth of 6–15 cm the number of larvae was observed least in August, May and July, and most in October and November. In the 16–25 cm soil layer the number of larvae remained approximately stable starting from April and during May, July, August, October and November. At a depth of 26–35 cm the number of larvae during the season was very low. In general, from April to November the number of larvae in the soil gradually increased.

In Table 2 the dynamics of the change in the amount of click beetle larvae according to the depth of soil layers is also presented. It becomes known that in April the number of larvae is greater at depths of 5 cm and 6–15 cm, and less in the 16–25 cm and 26–35 cm layers. In May, July, August, October and November they were observed mostly at depths of 6–15 cm and 16–25 cm. It can be seen from the table that the larvae of the field click beetle are mainly located at a depth of 16–25 cm in the soil. In these layers optimal temperature and humidity conditions are more favorable for their development.

Along with the theoretical significance of the obtained results, their practical importance is also great. Thus, knowing the soil layer of the larvae makes it possible to carry out pest control measures more purposefully and efficiently.

Conclusion

Observations show that the number of larvae of the field click beetle differs significantly as the season changes. The number of larvae at a depth of 5 cm in the soil is lowest in November, July and August, and highest in April and October. In the 6–15 cm layer the number of larvae was recorded as minimal in August, May and July, and maximal in October and November. At a depth of 16–25 cm the number of larvae remains relatively stable from April to November. In the 26–35 cm layer the number of larvae during the whole season has been very low. In general, from April to November the number of larvae in the soil shows a gradual increase.

Table 2 shows that depending on the depth of soil layers the number of larvae has different dynamics across different months. In April the number of larvae is mainly high at depths of 5 cm and 6–15 cm, and low in the 16–25 cm and 26–35 cm layers. In May, July, August, October and November they were observed mostly in the 6–15 cm and 16–25 cm layers. It becomes clear from the table that the larvae of the field click beetle mainly accumulate at a depth of 16–25 cm where optimal temperature and humidity conditions are provided for them. These results have both theoretical and practical importance. Knowing the soil layer where the larvae are located makes it possible to carry out pest control measures more purposefully and effectively.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 108–118
DOI: https://doi.org/10.36719/2707-1146/65/108-118

Upper Secondary Students' Perceptions of Underutilized Food Resources in Rwanda: Awareness, Attitudes, and Barriers to Utilization

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Abstract. *Underutilized food resources comprising neglected indigenous plants, animals, and fungi; hold substantial potential for improving food security, dietary diversity, and nutritional outcomes. Yet, they remain poorly integrated into mainstream diets, particularly among youth. This study investigated upper secondary students' perceptions of, and engagement with, underutilized food resources in Rwanda, with a focus on awareness levels, attitudes, and barriers to practical utilization. A mixed-methods design was employed, combining structured questionnaires administered to a stratified random sample of 52 students (drawn from a target population of 107 students) and 6 staff at Ecole Secondaire Saint Joseph le Travailleur, focus group discussions (n = 4 groups), and semi-structured interviews with teachers and school leaders. Data were analyzed using descriptive statistics in Microsoft Excel. Fourteen categories of underutilized food resources were identified across the Animalia, Plantae, and Fungi kingdoms. Regarding awareness, only 17% of students demonstrated comprehensive knowledge, 29% reported partial knowledge, and 54% had minimal knowledge. A comparable pattern emerged for actual consumption: 17% used these resources regularly, 29% occasionally, and 54% rarely. Barriers included limited availability in local markets, unfamiliarity with preparation methods, cultural taboos, and insufficient integration into school meal programs. A significant awareness-utilization gap exists among Rwandan secondary school students regarding underutilized food resources. Targeted educational interventions, curriculum integration, and school feeding program reforms are recommended to bridge this gap and improve dietary diversity and food security outcomes.*

Keywords: *underutilized food resources, student perceptions, food security, Rwanda, indigenous vegetables, dietary diversity & neglected crops*

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Received: 28 December 2025; Accepted: 5 March 2026; Published online: 25 April 2026

1. Introduction

Global food systems face mounting pressures from population growth, climate change, and the narrowing of dietary diversity. The world population is projected to reach approximately 10 billion by 2050, yet food production growth has not kept pace, and approximately 820 million people remain chronically undernourished (Adewoyin et al., 2017; Awoyinka et al., 1995). One underexplored strategy to address these twin challenges of food insecurity and nutritional deficiency is the promotion of underutilized food resources as edible species that are locally available but insufficiently exploited due to knowledge gaps, cultural barriers, or limited market integration (Bain et al., 2013; Brown et al., 2018).

Underutilized food resources are broadly defined as consumable organisms including plants, animals, and fungi that are available in a given ecosystem but not fully exploited, despite possessing nutritional, economic, and ecological value (Campbell & Reece, 2008). They differ from so-called 'alternative' foods in that they are not exotic imports but rather indigenous species embedded in local environments and cultural histories. Their potential to contribute to food security, malnutrition reduction, biodiversity conservation, and climate resilience has been increasingly recognized in scientific literature (Cardozo & Morales, 2019; Chauhan et al., 2023).

Globally, the distribution of underutilized food resources is broad but context-specific. In South and Southeast Asia, millets, buckwheat, and wild vegetables provide essential nutrients and enhance dietary diversity (Cullen et al., 2015). Across the Americas, quinoa, amaranth, and chayote are rich in protein, essential amino acids, and vitamins (Chauhan et al., 2023). In Africa, species such as Fonio, Teff, Baobab, Moringa, Bambara groundnut, and African yam bean remain chronically underexploited despite high nutritional profiles and resilience to local agro-ecological conditions (FAO, 2023; Galluzzi & López Noriega, 2014).

In Rwanda specifically, the agricultural sector supports over 70% of the population, yet national nutrition surveys consistently report high rates of micronutrient deficiencies, particularly among children and women of reproductive age (Giraldi & Hanazaki, 2014; Hoeschle-Zeledon et al., 2009). Rwanda harbors diverse indigenous food species including spider plant (isogi), amaranth (dodo), pumpkin leaves, cassava leaves, bean leaves, taro, and edible mushrooms that could meaningfully contribute to dietary diversity and food security if better integrated into local diets. Yet their utilization remains limited, and their nutritional potential largely unrealized.

Youth, and secondary school students in particular, represent a critical demographic for food systems transformation. Their dietary habits are still being formed, they are potential future agricultural actors, and schools provide structured platforms for nutrition education. Understanding how adolescent students perceive underutilized food resources; what they know, how they feel about consuming these foods, and what prevents them from doing so, is therefore a necessary precondition for designing effective interventions (Landim et al., 2024; MINAGRI, 2018).

Despite growing research on underutilized food resources globally, studies focusing specifically on youth perceptions within a Rwandan secondary school context are scarce. This study seeks to fill that gap by investigating upper secondary students' awareness, attitudes, and actual utilization of underutilized food resources at Ecole Secondaire Saint Joseph le Travailleur (ESSJT), a vocational school with a Food and Beverage Operations track. The study pursued three specific objectives: (1) to identify and classify underutilized food resources present in Rwanda; (2) to analyze students' perceptions of these resources; and (3) to assess the extent and barriers of their actual utilization among students.

2. Materials and Methods

2.1 Study Design and Setting

This study adopted a descriptive, mixed-methods research design, integrating both quantitative survey data and qualitative insights from focus group discussions (FGDs) and semi-structured interviews. The research was conducted at Ecole Secondaire Saint Joseph le Travailleur (ESSJT), a secondary school in Rwanda offering a Food and Beverage Operations (FBO) specialization at upper secondary level (Levels 3 and 4). The school was purposively selected as a relevant study site given its food-related curriculum, which positions students to have potentially greater exposure to food diversity and nutrition concepts than the general secondary school population.

2.2 Target Population and Sampling

The target population comprised all students enrolled in the Food and Beverage Operations track at ESSJT, as well as teachers and school leaders with relevant subject matter knowledge, totaling 113 individuals. The population distribution is presented in Table 1.

Table 1
Research population distribution, Ecole Secondaire Saint Joseph le Travailleur

Category	Level 3 (2 classes)	Level 4	Teachers & Leaders	Total
Male students	12	11	—	23
Female students	49	35	—	84
Teachers	—	—	4	4
School leaders	—	—	2	2
Total	**61**	**46**	**6**	**113**

Source: Primary data, 2025

The sample size for the student stratum was calculated using Yamane's (1967) formula for finite populations:

$$n = N / (1 + N \cdot e^2)$$

Where N = 107 (total student population) and e = 0.1 (margin of error). This yielded a student sample of n = 52. All four teachers and both school leaders were included as census respondents, yielding a total sample of 58 participants. Stratified random sampling was applied across the three class levels to ensure proportional representation by gender and class.

2.3 Data Collection Instruments

Three complementary instruments were used. First, a structured questionnaire with both closed (Likert-scale and checklist) and open-ended items was administered to 52 student respondents. The questionnaire covered: (a) respondent sociodemographic characteristics; (b) identification of known underutilized food resources; (c) perceptions and attitudes toward these resources; and (d) frequency of consumption and barriers to utilization. Second, focus group discussions (FGDs) were conducted with four groups of 13 students each, guided by a semi-structured protocol exploring knowledge depth, cultural influences, and suggested interventions. Third, semi-structured individual interviews were conducted with four teachers and two school leaders to obtain expert and institutional perspectives on underutilized food resource education and integration. Secondary data, including scientific literature and internet-sourced documentation, were additionally used to compile a comprehensive catalogue of underutilized food resources relevant to Rwanda's agro-ecological context.

2.4 Data Analysis

Quantitative data from student questionnaires were entered and analyzed in Microsoft Excel, generating descriptive statistics including frequencies and percentages. Qualitative data from FGDs and interviews were analyzed thematically, with emerging codes organized into overarching themes aligned with the study objectives. Convergence and divergence between quantitative and qualitative findings were examined to enhance the validity of interpretations.

2.5 Ethical Considerations

Participation was voluntary, and informed consent was obtained from all respondents. For minor participants, assent was obtained alongside parental/guardian consent through the school administration. Confidentiality and anonymity were maintained throughout data collection, analysis, and reporting. No personal identifiers were retained in the dataset.

3. Results

3.1 Identification and Classification of Underutilized Food Resources in Rwanda

The first objective of the study was to identify and classify underutilized food resources available in Rwanda. Drawing on documentary review and student self-reports, the research identified 14 categories of underutilized food resources, organized according to their biological kingdom: Animalia, Plantae, and Fungi (Table 2).

Table 2

Classification of identified underutilized food resources in Rwanda

Kingdom	Category	Common Name(s)	Scientific Name / Local Name	Nutritional Highlights
Animalia	Insects	Flying termites	*Macrotermes spp.*	High protein, fat, micronutrients
Animalia	Birds	Dove and pigeon	*Edible spp.*	Lean protein, calcium
Animalia	Rodents	Mole rat	*Tachyoryctes splendens (ifuku)*	Protein, iron
Animalia	Small mammals	Guinea pig	*Cavia porcellus (sumbirigi)*	High-quality protein, B-vitamins
Animalia	Fish	Walking catfish	*Clarias gariepinus*	Protein, omega fatty acids
Plantae	Leafy vegetables	Spider plant	*Cleome gynandra (isogi)*	Iron, beta-carotene, folate
Plantae	Leafy vegetables	Amaranth leaves	*Amaranthus spp. (dodo)*	Protein, iron, vitamins A & C
Plantae	Leafy vegetables	Pumpkin leaves	*Cucurbita pepo*	Vitamins A, C, calcium
Plantae	Leafy vegetables	Cassava leaves	*Manihot esculenta*	Protein, minerals (requires detox)

Kingdom	Category	Common Name(s)	Scientific Name / Local Name	Nutritional Highlights
Plantae	Leafy vegetables	Bean leaves	*Phaseolus vulgaris (ibijumba)*	Vitamin A, iron, zinc
Plantae	Corms/tubers	Taro	*Colocasia esculenta*	Carbohydrates, vitamins, minerals
Plantae	Wild fruits	African nightshade	*Solanum nigrum*	Vitamins, antioxidants
Plantae	Cereals	Finger millet	*Eleusine coracana*	Calcium, iron, dietary fiber
Fungi	Mushrooms	Wild edible mushrooms	*Various spp.*	Protein, B-vitamins, trace minerals

Source: Field data and documentary review, 2025

Many of these species are well-documented in the scientific literature for their nutritional density, climate resilience, and suitability for local growing conditions. For instance, amaranth (Amaranthus spp.) is widely recognized as a high-protein, iron- and vitamin-rich crop well-adapted to semi-arid conditions (Tyagi et al., 2017). Cassava leaves (Manihot esculenta) have been documented as a significant source of protein in sub-Saharan Africa (Awoyinka et al., 1995). Bean leaves represent an inexpensive but nutritionally valuable source of vitamin A, iron, and zinc (Wangila, 2014), while taro leaves provide a range of essential vitamins and minerals (Chauhan et al., 2023). Flying termites and guinea pigs, among the animal resources, are associated with high protein and nutritional quality (Cardozo & Morales, 2019; Wallenbeck & Jönsson, 2016).

3.2 Students' Perceptions and Awareness of Underutilized Food Resources

The second objective examined students' perceptions and level of knowledge about underutilized food resources. Focus group discussions and individual questionnaire responses produced a consistent pattern in which students hold broadly positive attitudes toward underutilized foods but possess varying and often superficial levels of knowledge.

As illustrated in Figure 1, of the 52 students surveyed, 9 (17%) demonstrated comprehensive knowledge. They could identify multiple species, describe their nutritional benefits, and articulate preparation methods. Fifteen students (29%) had partial knowledge because they recognized some species but lacked depth on nutritional or culinary dimensions. The majority, 28 students (54%), had minimal knowledge, unable to name or describe most underutilized food resources or articulate their benefits.

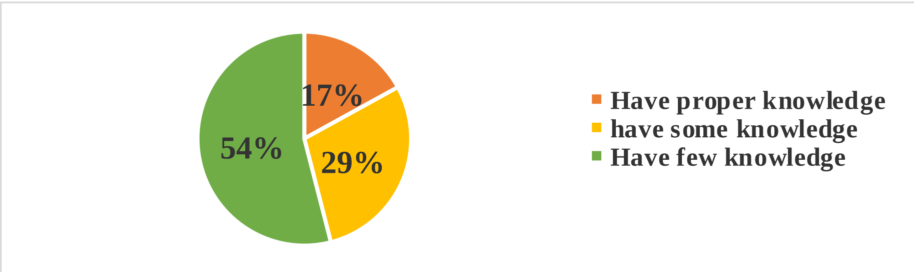

Figure 1

Students' self-reported knowledge levels of underutilized food resources (n = 52).

Source: Field data, 2025

[Figure 1 — Pie chart: Distribution of students' knowledge levels on underutilized food resources (n = 52). Categories: Comprehensive 17%, Partial 29%, Minimal 54%. Insert actual figure file here.]

Qualitatively, FGD participants consistently expressed positive attitudes toward underutilized foods when presented with information about them. Students acknowledged their nutritional value and cultural significance, often referencing grandparents or rural relatives who consumed them regularly. However, they simultaneously described social norms particularly peer influence and the perceived 'modernity' of processed and imported foods as discouraging factors. This finding aligns with Brown et al. (2018), who found that positive perceptions alone are insufficient to drive dietary behavior change without supportive structural and social interventions.

Teachers interviewed noted that the Food and Beverage Operations curriculum contains limited content on indigenous and underutilized species, and that students' awareness was largely driven by family background rather than formal education. School leaders acknowledged interest in expanding the curriculum but cited resource constraints.

3.3 Exploitation and Consumption of Underutilized Food Resources

The third objective assessed the degree to which students actually consume underutilized food resources in their daily lives. Findings revealed a pronounced gap between awareness and practice. As shown in Figure 2, only 9 students (17%) reported regularly incorporating underutilized food resources into their diet, while 15 (29%) consumed them occasionally, and 28 students (54%) rarely or never consumed them.

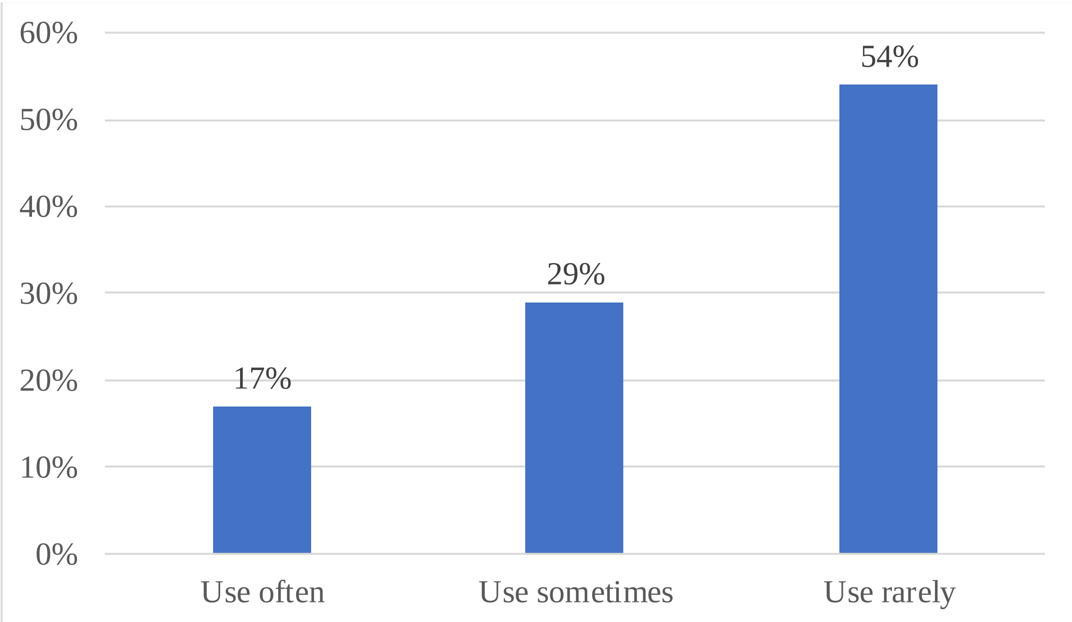

Figure 2

Frequency of consumption of underutilized food resources among students (n = 52).

Source: Field data, 2025

[Figure 2 — Bar chart: Frequency of consumption of underutilized food resources among students (n = 52). Categories: Regular 17%, Occasional 29%, Rare/Never 54%. Insert actual figure file here.]

Multiple barriers to utilization were identified through both the questionnaire and FGD responses. Students cited the following as the most significant obstacles. The limited availability Explained with many species that are not readily found in local markets or near students' homes, particularly for students from urban areas. Unfamiliarity with preparation methods as another barrier where students reported not knowing how to safely and palatably prepare many species, particularly leafy vegetables (e.g., cassava and taro leaves require specific detoxification techniques) and animal products (e.g., walking catfish, flying termites). In terms of cultural and social taboos, several students described family or community restrictions on consuming certain animals (e.g., mole rat, guinea pig) or plant species, particularly among youth. An absence from school meals**,** the statement said none of the identified underutilized species were part of the school's regular meal program, removing an important institutional pathway for exposure. Lastly, aesthetic and social preferences or peer influence and aspirational preferences for 'modern' processed foods reduced motivation to consume indigenous species.

Students who did consume these resources regularly were significantly more likely to come from rural backgrounds, report family members who also consumed them, or have received prior instruction on preparation methods, highlighting the role of social learning and early exposure in shaping utilization behavior (Hoeschle-Zeledon et al., 2009; Nguyen & Lee, 2019).

4. Discussion

This study provides empirical evidence of a well-documented but understudied phenomenon in the Rwandan context: the gap between positive perceptions of underutilized food resources and their limited practical adoption among secondary school youth. The finding that 54% of students have minimal knowledge and rarely consume these foods, despite attending a vocational school with a food specialization, is particularly striking and underscores the depth of the challenge.

A particularly noteworthy finding of this study is the striking congruence between the results of students' perceptions and awareness (Section 3.2) and their actual exploitation and consumption behavior (Section 3.3). In both dimensions, respondents distributed themselves in virtually identical proportions: 17% demonstrated comprehensive knowledge and regular consumption, 29% exhibited partial knowledge and occasional consumption, and 54% fell into the minimal knowledge and rare/never consumption categories. This parallel agreement pattern strongly suggests that awareness and behavior are deeply interlinked. students who know more about underutilized food resources are also those who consume them most frequently, and conversely, those with limited awareness are consistently those who rarely or never incorporate these foods into their diets. This alignment is consistent with the knowledge-attitude-practice (KAP) framework, which posits that knowledge acquisition is a foundational precursor to behavioral adoption in nutritional contexts (Landim et al., 2024).

Similar congruence between knowledge levels and consumption frequency has been documented in studies of indigenous food utilization among youth in sub-Saharan Africa. Adewoyin et al. (2017) reported that rural Nigerian youth who demonstrated greater familiarity with underutilized indigenous vegetables were significantly more likely to consume them, reinforcing the notion that awareness, while insufficient on its own, tracks closely with dietary behavior. Likewise, Giraldi and Hanazaki (2014) observed that communities with richer ethnobotanical knowledge maintained stronger connections to traditional food consumption practices. In the present study, the identical percentage distributions across knowledge and consumption categories as a phenomenon not commonly reported with such precision in the literature may reflect the role of experiential learning confirming that students likely come to know underutilized foods primarily through the experience of consuming them in family or community settings, rather than through formal education (Hoeschle-Zeledon et al., 2009; Nguyen & Lee, 2019). This interpretation is further supported by the qualitative findings, wherein FGD participants attributed their awareness of underutilized resources primarily to grandparents and rural relatives rather than school curricula. The convergence of awareness and practice data thus has direct implications for intervention design: increasing knowledge alone, without simultaneously creating opportunities for exposure and consumption, is unlikely to shift behavioral patterns. Integrated approaches that combine nutrition education with practical cooking experiences and school meal diversification are therefore essential (Padulosi et al., 2013; Smith & Jones, 2020).

The pattern mirrors findings from analogous studies in West Africa, where Adewoyin et al. (2017) found that rural youth in Osun State, Nigeria demonstrated similarly low consumption of underutilized indigenous vegetables despite expressed familiarity with some species. It also aligns with Giraldi and Hanazaki (2014), who documented a consistent disconnect between ethnobotanical knowledge and dietary behavior in traditional communities. Collectively, these findings suggest that knowledge and positive attitudes are necessary but not sufficient conditions for behavioral change in food consumption to prove a conclusion consistent with sociological models of food behavior (Landim et al., 2024).

The barriers identified in this study such as limited market access, unfamiliarity with preparation, cultural constraints, and absence from school meal programs are well documented in the literature on underutilized food resources globally (Galluzzi & López Noriega, 2014; Nguyen & Lee, 2019; Hoeschle-Zeledon et al., 2009). However, their presence in a school with a dedicated food and beverage curriculum is particularly notable, suggesting that formal vocational education in Rwanda does not yet provide adequate coverage of indigenous food resources, a gap that represents both a challenge and an opportunity.

The cultural dimensions of underutilization deserve particular attention. Several students referenced taboos or family restrictions around specific animal-based underutilized resources, including the mole rat (ifuku) and guinea pig (sumbirigi). These dynamics reflect broader cultural food systems in which identity, religion, and social norms shape individual dietary choices in ways that transcend purely nutritional or economic reasoning (Landim et al., 2024). Educational interventions targeting underutilized food promotion must therefore be culturally sensitive and community-informed rather than purely information-based.

Importantly, this study also reveals significant potential for change. The 17% of students with comprehensive knowledge and regular consumption habits demonstrate that these resources are not inherently unacceptable to youth but rather that adoption is strongly associated with early exposure, family practice, and cooking confidence. These findings point toward actionable entry points for intervention such as curricula reform, practical cooking workshops, school feeding program diversification, and community engagement can together address the interrelated knowledge, skills, and social dimensions of underutilization.

From a policy perspective, Rwanda's national nutrition and food security programs including those coordinated through MINAGRI and the Rwanda Agriculture and Animal Resources Development Board (RAB) are well-positioned to support underutilized food resource promotion. Ongoing initiatives such as the promotion of rabbit and guinea pig farming indicate growing institutional awareness of the issue, but these efforts require reinforcement through the education sector to reach youth systematically.

A limitation of this study is its single-school, single-region scope, which may constrain the generalizability of findings to the broader Rwandan adolescent population. Additionally, the reliance on self-reported consumption data introduces potential social desirability bias. Future studies should employ multi-site, regionally stratified designs and, where feasible, dietary recall or food frequency questionnaires to provide more objective consumption estimates.

5. Conclusion

This study investigated upper secondary students' perceptions of underutilized food resources at Ecole Secondaire Saint Joseph le Travailleur, Rwanda. Fourteen categories of underutilized resources were identified across the Animalia, Plantae, and Fungi kingdoms, many of which are nutritionally dense and well-suited to Rwanda's agro-ecological conditions. The findings reveal that the majority of students (54%) have minimal knowledge of these resources and rarely consume them, despite generally positive attitudes constituting a significant awareness-utilization gap. The barriers to utilization are multifaceted, encompassing knowledge deficits, practical skills gaps, cultural constraints, limited market access, and absence from school meal programs. Addressing these barriers requires coordinated action across the education, agriculture, and health sectors, underpinned by culturally sensitive, evidence-based approaches. Schools particularly those with vocational food and nutrition tracks represent high-leverage sites for intervention.

Based on these findings, the following recommendations are directed toward relevant stakeholders:

1. Ministry of Education and Rwanda TVET Board (RTB): Integrate underutilized indigenous food resource content into the Food and Beverage Operations curriculum, including identification, nutritional value, safe preparation, and cultural context; mandate practical cooking workshops as part of vocational competency training.
2. Ministry of Agriculture (MINAGRI) and Rwanda Agriculture Board (RAB): Scale up promotion and production support for priority underutilized species through extension services and school outreach; develop and disseminate accessible knowledge materials on underutilized food resources for schools and communities.
3. Ministry of Health and Rwanda Biomedical Centre (RBC): Incorporate promotion of underutilized food resources into national nutrition campaigns; conduct targeted nutrition education in schools in partnership with school health programs.
4. School Administrations: Diversify school meal programs to include underutilized indigenous foods; establish school demonstration gardens featuring underutilized species as educational and food production resources.

Directions for Future Research

Future studies should: (1) assess the nutritional impact of increased consumption of specific underutilized resources on student health outcomes; (2) evaluate the effectiveness of curriculum-based interventions in changing student knowledge and consumption behavior; (3) explore the economic value of underutilized food resources for smallholder farmers in Rwanda; and (4) investigate the role of underutilized food resources in climate adaptation and sustainable agriculture at national scale.

Declarations

Ethics approval and consent to participate: Participation was voluntary. Informed consent was obtained from all respondents. For minor participants, assent was obtained alongside parental/guardian consent through the school administration. No personal identifiers were retained.

Consent for publication: Not applicable.

Availability of data and materials: The datasets supporting the conclusions of this article are available from the corresponding author upon reasonable request.

Competing interests: The authors declare no competing interests.

Funding: This research received no external funding.

Authors' contributions: EN, BN, JK and CN conceptualized the study and led data collection. SH, EH, LI, and AU contributed to data collection, analysis, and manuscript preparation. All authors reviewed and approved the final manuscript.

Acknowledgements: The authors express gratitude to the administration, teachers, and students of Ecole Secondaire Saint Joseph le Travailleur for their participation and support.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 119–123
DOI: https://doi.org/10.36719/2707-1146/65/119-123

Soil Degradation and Food Security: Interlinked Global Challenges and Pathways Toward Sustainability

Seyidnisa Aliyeva

Abstract. *Soil degradation represents one of the most pressing environmental challenges of the contemporary world, significantly undermining agricultural productivity and threatening global food security. As a vital natural resource, soil plays a central role in sustaining ecosystems, supporting crop production, and maintaining biodiversity. However, increasing anthropogenic pressures such as unsustainable agricultural practices, deforestation, overgrazing, and rapid urbanization have accelerated the degradation of soil resources across the globe. This paper examines the complex and multidimensional relationship between soil degradation and food security, emphasizing the environmental, economic, and social implications of declining soil health. It further explores how climate change exacerbates soil degradation processes and intensifies food insecurity, particularly in vulnerable regions. The study highlights the importance of sustainable land management practices, policy interventions, and technological innovations in mitigating soil degradation and ensuring long-term food security. By adopting an integrated and holistic approach, it is possible to restore soil health and build resilient food systems capable of meeting the demands of a growing global population.*

Keywords: *soil degradation, food security, sustainable agriculture, land management, climate change*

Introduction

Soil constitutes the foundation of terrestrial life, serving as a dynamic and complex system that supports plant growth, regulates water cycles, and facilitates nutrient exchange within ecosystems. Despite its critical importance, soil is increasingly subjected to degradation processes that diminish its productive capacity and ecological functions. Soil degradation is not merely an environmental issue but also a socio-economic challenge with far-reaching consequences for global food systems. As the global population continues to grow and demand for food intensifies, the pressure on land resources has reached unprecedented levels, resulting in unsustainable exploitation and widespread deterioration of soil quality (FAO, 2015).

The concept of soil degradation encompasses a range of physical, chemical, and biological processes that collectively reduce soil fertility and productivity. Physical degradation often manifests in the form of erosion, compaction, and structural breakdown, leading to the loss of topsoil and reduced water infiltration capacity. Chemical degradation involves nutrient depletion, salinization, and acidification, all of which impair soil fertility and limit plant growth.

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Received: 11 January 2026; Accepted: 24 March 2026; Published online: 25 April 2026

Biological degradation, on the other hand, refers to the decline in soil organic matter and biodiversity, which are essential for maintaining soil structure and nutrient cycling. These processes are often interrelated and tend to reinforce each other, creating a cycle of degradation that is difficult to reverse.

Human activities have been identified as the primary drivers of soil degradation. Intensive agricultural practices, including monocropping, excessive use of chemical fertilizers and pesticides, and improper irrigation techniques, have significantly contributed to soil deterioration. Deforestation and land clearing for agricultural expansion disrupt natural ecosystems and expose soil to erosion and nutrient loss. Overgrazing by livestock further exacerbates soil compaction and vegetation loss, while urbanization and industrialization lead to soil sealing and contamination. These activities not only degrade soil but also reduce its capacity to support sustainable agricultural production (Lal, 2015).

Methods

The link between soil degradation and food security is both direct and profound. Food security is fundamentally dependent on the availability of fertile and productive land. When soil quality declines, agricultural yields decrease, leading to reduced food availability. This, in turn, drives up food prices and limits access to nutritious food, particularly for vulnerable populations. In many developing regions, where agriculture is the primary source of livelihood, soil degradation directly threatens economic stability and increases the risk of poverty and hunger. Moreover, degraded soils often produce crops with lower nutritional value, contributing to micronutrient deficiencies and adverse health outcomes (UNEP, 2023).

Climate change further complicates the relationship between soil degradation and food security by intensifying environmental stressors. Rising temperatures, changing precipitation patterns, and the increased frequency of extreme weather events such as droughts and floods accelerate soil degradation processes. For instance, heavy rainfall can lead to severe soil erosion, while prolonged droughts reduce soil moisture and organic matter content. At the same time, degraded soils release stored carbon into the atmosphere, contributing to greenhouse gas emissions and reinforcing the cycle of climate change. This interconnected dynamic highlights the need for integrated strategies that address both soil degradation and climate change simultaneously (IPCC, 2021).

The global scale of soil degradation presents significant challenges for food security. Large areas of arable land have already been affected, and the rate of degradation continues to increase. In regions such as Sub-Saharan Africa and South Asia, where population growth is rapid and agricultural systems are highly dependent on natural resources, the impacts of soil degradation are particularly severe. These regions often lack the financial and technological capacity to implement effective soil management practices, making them more vulnerable to food insecurity. At the same time, developed regions face their own challenges, including soil contamination, loss of organic matter, and unsustainable land use patterns (Crosson & Anderson, 1999).

The economic implications of soil degradation are substantial. Reduced agricultural productivity leads to increased production costs as farmers rely more heavily on external inputs such as fertilizers and irrigation. This not only places a financial burden on farmers but also contributes to environmental pollution and resource depletion. In the long term, soil degradation can result in the loss of arable land, forcing communities to migrate and exacerbating social inequalities. The cumulative economic impact at the global level is significant, affecting food markets, trade, and overall economic stability.

Addressing soil degradation requires a comprehensive and sustainable approach that integrates environmental, economic, and social considerations. Sustainable land management practices play a crucial role in restoring soil health and enhancing agricultural productivity. Techniques such as conservation agriculture, crop rotation, agroforestry, and organic farming help maintain soil structure, improve nutrient content, and reduce erosion. These practices not only enhance soil resilience but also contribute to climate change mitigation by increasing carbon sequestration (Nkonya et al., 2016).

Technological innovations also offer promising solutions for combating soil degradation. Precision agriculture, for example, enables farmers to optimize the use of inputs by applying fertilizers and water more efficiently. Soil monitoring technologies provide valuable data on soil conditions, allowing for informed decision-making and targeted interventions. Additionally, the use of organic amendments such as compost and biochar can improve soil fertility and structure, promoting sustainable agricultural production (Montgomery, 2007).

Policy interventions and institutional support are equally important in addressing soil degradation. Governments and international organizations must prioritize soil conservation and sustainable land management in their development agendas. This includes providing financial incentives, technical assistance, and education programs to encourage the adoption of sustainable practices. International cooperation is also essential, as soil degradation is a global issue that transcends national boundaries. Collaborative efforts can facilitate knowledge sharing, capacity building, and the development of innovative solutions (Gomiero, 2016).

Community involvement and local knowledge play a critical role in the successful implementation of soil conservation strategies. Farmers and local communities possess valuable insights into land management practices that are adapted to specific environmental conditions (Doran & Zeiss, 2000). Empowering these stakeholders through education and participatory approaches can enhance the effectiveness and sustainability of soil restoration efforts. Furthermore, raising public awareness about the importance of soil health can foster a culture of environmental stewardship and promote responsible land use (Sahu & Mohanty, 2021).

Results

The future of food security is inextricably linked to the health of soil resources. As the global population continues to grow, the demand for food will increase, placing additional pressure on already degraded land. Without immediate and coordinated action, the capacity of soil to support agricultural production will continue to decline, exacerbating food insecurity and environmental degradation (Seddon, 2020).

However, with the adoption of sustainable practices, technological advancements, and effective policies, it is possible to reverse the trend of soil degradation and build resilient food systems (Montanarella & Panagos, 2020).

Discussion

Soil degradation and food security are deeply interconnected processes that reflect both environmental and socio-economic dynamics at local, regional, and global scales. The findings of this study confirm that soil degradation is not merely a biophysical phenomenon but a multidimensional challenge shaped by human activity, policy frameworks, and climate variability. The decline in soil quality—manifested through erosion, salinization, nutrient depletion, and contamination—directly reduces agricultural productivity and threatens the stability of food systems.

One of the central issues highlighted in this context is the role of unsustainable agricultural practices. Intensive land use, excessive application of chemical fertilizers, and improper irrigation methods accelerate soil degradation. In regions such as Azerbaijan, where agriculture plays a significant role in economic development and rural livelihoods, these practices intensify pressure on already vulnerable land resources. Overgrazing and deforestation further exacerbate the situation by disrupting natural soil regeneration processes and increasing susceptibility to erosion.

Climate change acts as a significant multiplier of soil degradation. Rising temperatures, irregular precipitation patterns, and increased frequency of extreme weather events contribute to the deterioration of soil structure and fertility. For instance, prolonged droughts reduce soil moisture, while heavy rainfall can intensify erosion. These changes not only reduce crop yields but also create uncertainty in food production systems, thereby undermining food security.

Conclusion

The issue of soil degradation, when examined in its full complexity, reveals itself not merely as an environmental concern but as a deeply interconnected global crisis with profound implications for food security, economic stability, and human well-being. Throughout this study, it has become evident that soil is far more than a passive medium for plant growth; it is a living, dynamic system that underpins agricultural productivity, ecological balance, and the sustainability of human societies. The degradation of this vital resource, therefore, represents a direct threat not only to current food systems but also to the long-term resilience of global development pathways.

One of the most critical insights emerging from the analysis is the inherently systemic nature of soil degradation. It does not occur in isolation but rather as a consequence of cumulative pressures arising from human activities, economic systems, and environmental change. Unsustainable agricultural practices, driven by the need to maximize short-term yields, have led to widespread nutrient depletion, erosion, and loss of soil structure. These practices are often reinforced by market dynamics and policy frameworks that prioritize productivity over sustainability. As a result, soil degradation becomes embedded within broader economic and institutional systems, making it more difficult to address through isolated interventions.

At the same time, the relationship between soil degradation and food security is shown to be both direct and multifaceted. Degraded soils lead to declining crop yields, which in turn reduce food availability at local, national, and global levels. However, the impact extends beyond mere quantity. The nutritional quality of food is also compromised, as soils deficient in essential nutrients produce crops with lower micronutrient content. This has significant implications for public health, particularly in regions already affected by malnutrition and food insecurity. In this sense, soil degradation contributes not only to hunger but also to hidden hunger, characterized by deficiencies in vitamins and minerals that are essential for human development.

Furthermore, the economic consequences of soil degradation are substantial and far-reaching. Farmers operating on degraded land often face increasing production costs as they attempt to compensate for declining soil fertility through the use of fertilizers, irrigation, and other inputs. While such measures may provide short-term relief, they frequently exacerbate environmental degradation and create a cycle of dependency that is both economically and ecologically unsustainable. For smallholder farmers, who constitute a significant proportion of the agricultural workforce in many developing countries, these challenges can lead to reduced incomes, increased vulnerability, and, ultimately, the erosion of livelihoods. At a broader scale, declining agricultural productivity can disrupt food markets, contribute to price volatility, and strain national economies.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 124–131
DOI: https://doi.org/10.36719/2707-1146/65/124-131

Phase Relations in the Ag_8SiS_6 - Ag_8SiSe_6 System and Characterization of Solid Solutions

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Abstract. *Argyrodite-type compounds and the phases derived from them represent environmentally benign and valuable functional materials exhibiting a wide range of properties, including thermoelectric, photoelectric, and optical characteristics. In addition, these materials demonstrate ionic conductivity through Cu^+ and Ag^+ ions, which makes them promising candidates for application as electrode or electrolyte materials in ion-selective electrodes, various types of batteries, displays, and sensors. In this work, the phase equilibria of the Ag_8SiS_6–Ag_8SiSe_6 system were investigated using differential thermal analysis and X-ray diffraction methods, and the corresponding T–x phase diagram was constructed. The system was found to be quasi-binary and is characterized by the formation of an extended region of solid solutions between the HT-Ag8SiS6 and HT-Ag8SiSe6 compounds. The polymorphic transition temperature of Ag8SiS6 decreases with increasing formation of solid solutions. It was determined that at room temperature the homogeneity region of the δ-phase extends within the composition range of 70–90 mol% Ag8SiSe6. Furthermore, the lattice parameters of the obtained solid solutions were calculated from X-ray diffraction data, revealing a linear dependence on composition.*

Keywords: *silver-silicon sulfide, silver-silicon selenide, argyrodite-like compounds, DTA, XRD, phase equilibria, polymorphic transformation*

Introduction

Binary and more complex chalcogenides formed by copper and silver with p-block elements are at the center of researchers' attention due to their thermoelectric, optical, photoelectric, and other functional properties (Khan, 2023; Puthran, 2024; Li, 2024; Portniagin, 2025). One of the important classes of these multicomponent materials is the argyrodite family compounds with the general formula $A^{I}_8B^{IV}X_6$ (A^I-Cu, Ag; B^{IV}-Si, Ge, Sn; X-S, Se, Te) (Wang, 2024; Parashchuk, 2025; Ghata, 2025). A distinctive feature of argyrodite-type compounds is the occurrence of polymorphic phase transitions at comparatively low temperatures (≤ 530 K). The low-temperature forms crystallize in ordered crystal structures with reduced symmetry, while the high-temperature modifications typically possess a cubic lattice structure (Kuhs, 1979; Bindi, 2018; Babanly, 2024).

These compounds are characterized by a rigid anion framework constructed from tetrahedrally coordinated [SiX_4] units (X = S, Se) and a highly disordered sublattice of mobile Ag^+ cations. Such a unique crystal structure results in high ionic conductivity as well as favorable optical, thermoelectric, and other physical properties.

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Received: 7 January 2026; Accepted: 24 March 2026; Published online: 25 April 2026

Due to the structural features of their high-temperature phases, argyrodite compounds exhibit superionic conductivity, where copper and silver ions demonstrate high mobility, leading to large values of cationic conductivity and ionic diffusion in the solid state (Shen, 2023; Studenyak, 2020; Kang, 2026; Ren, 2023). These properties make such materials promising for applications as solid electrolytes, ion-selective electrodes, thermoelectric energy conversion materials, and components of photoelectric and optoelectronic devices (Lin, 2024; Wei, 2024; Dallas, 2025; Bustamante, 2025; Li, 2020). Due to these properties, argyrodit-based systems have been extensively studied by various research groups. In previous studies (Bayramova, 2022; Amiraslanova, 2023; Bayramova, 2023; Poladova, 2025; Huseynova, 2025; Ismayilova, 2025), phase equilibria and phase transitions in systems composed of argyrodite-type compounds were experimentally investigated. These studies revealed that such systems are typically characterized by the formation of wide or even unlimited substitutional solid solutions.

The objective of the present work was to examine the phase equilibria in the Ag_8SiS_6–Ag_8SiSe_6 system in order to obtain new variable-composition phases based on silicon-containing argyrodites. The initial compounds forming this system have been previously studied in considerable detail.

The compound Ag_8SiS_6 melts congruently at 1213 K (Gorochov, 1968), 1223 K (Boivin, 1967), 1232 K (Cambi, 1961), and 1243 K (Venkatraman, 1995), while its polymorphic transition temperature is reported as 507 K (Gorochov, 1968; Boivin, 1967) and 510 K (Venkatraman, 1995). The low-temperature modification of Ag_8SiS_6 crystallizes in the orthorhombic system with the following lattice parameters: space group $Pna2_1$, a = 1.5024, b = 0.7428, c = 1.0533 nm (Krebs, 1977); a = 1.5043, b = 0.7452, c = 1.0565 nm (Kuhs, 1979). The high-temperature modification has a cubic structure: space group $F\bar{4}3m$, a = 1.063 nm (Gorochov, 1968).

The compound Ag_8SiSe_6 melts congruently at 1258 K (Venkatraman, 1995), 1278 K (Amiraslanova, 2023), 1203 K (Gorochov, 1968; Hofmann, 1988), 1268 K (Piskach, 2006), and its polymorphic transition temperature is reported as 315 K (Amiraslanova, 2023) and 354 K (Amiraslanova, 2023). Three modifications have been reported for this compound (Liang, 2020; Gorochov, 1968; Hofmann, 1988; Heep, 2017). The high-temperature modification crystallizes in a face-centered cubic lattice (space group $F\bar{4}3m$, a = 1.097 nm (Gorochov, 1968; Hofmann, 1988), a = 1.09413(1) nm (Heep, 2017). The intermediate modification has a simple cubic structure (space group $P2_13$ (Heep, 2017) or $P4_232$, a = 1.087 nm (Gorochov, 1968). The low-temperature modification crystallizes in a tetragonal structure (space group $I\bar{4}m2$, a = 0.7706, c = 1.10141 nm (Gorochov, 1968; Hofmann, 1988). However, Jiang and co-authors (Jiang, 2020) reported that the powder X-ray diffraction pattern of LT-Ag_8SiSe_6 cannot be satisfactorily indexed using this structural model. The authors identified the presence of two different sets of reflections in the diffractogram and showed that most of the peaks can be indexed in the orthorhombic system with space group $Pmn2_1$. In addition, weak-intensity peaks observed in the angular regions of 33.5°, 34.7°, and 37.0° were attributed to the orthorhombic RT-Ag_2Se phase (Jiang, 2020).

Materials and Methods

The initial compounds were synthesized by melting high-purity elements (at least 99.999 wt.% purity) Ag, Si, S, and Se in evacuated quartz ampoules. To prevent the reaction of silicon with the quartz ampoule, the inner surface of the ampoule was carbon-coated (graphitized) at the beginning of the process.

Due to the high vapor pressure of sulfur and selenium, the synthesis was performed in a two-zone regime in an inclined furnace. The temperature of the lower "hot zone" was set 50 K above the melting point of the compound, namely 1280 K for Ag_8SiS_6 and 1300 K for Ag_8SiSe_6. The upper "cold zone" was heated to a temperature 50–100 K below the boiling point of the appropriate chalcogen. In the cold zone, sulfur and selenium vapors condensed and returned to the reaction zone. After the main portion of the chalcogen had reacted, the ampoule was completely placed inside the furnace, kept for 2–3 hours, and then cooled to room temperature in the switched-off furnace.

The purity of the synthesized compounds was confirmed by differential thermal analysis (DTA) and X-ray diffraction (XRD). The obtained analytical results for both compounds were found to be in good agreement with previously reported literature data.

Alloys of the Ag_8SiS_6–Ag_8SiSe_6 system were synthesized by melting appropriate stoichiometric amounts of the pre-synthesized and well-characterized starting compounds. To achieve equilibrium, the samples were annealed at 800 K for an extended period (500 hours). Two series of samples for each composition were synthesized. The first series was furnace-cooled after thermal treatment (the furnace was switched off and the samples were allowed to cool gradually), whereas the second series was water-quenched from 800 K by rapidly immersing the ampoule in cold water. The synthesized samples were investigated using DTA and XRD methods.

Differential thermal analysis was performed using a NETZSCH 404 F1 Pegasus instrument and a multi-channel DTA device based on a “TC-08 Thermocouple Data Logger” with a temperature measurement accuracy of ±2 K. The experimental data were processed using NETZSCH Proteus software. X-ray phase analysis was performed at room temperature in the 2θ range of 5–75° using $CuK\alpha_1$ radiation on a Bruker D2 PHASER diffractometer. The obtained diffraction patterns were analyzed with TOPAS V3.0 software, and the lattice parameters were subsequently determined.

Results and Discussion

Both series of alloys in the Ag_8SiS_6–Ag_8SiSe_6 system were examined using differential thermal DTA and XRD techniques. The experimental results showed that complete mutual solubility exists between the high-temperature phases of the initial compounds in the Ag_8SiS_6–Ag_8SiSe_6 system. Based on their low-temperature modifications, wide solid solutions are formed. The resulting powder diffraction patterns are shown in Figure 1. It was established that the diffraction patterns of samples within the composition range of 70–90 mol% Ag_8SiSe_6 correspond to a cubic system and qualitatively differ from those of the initial compounds. Samples containing 10–60 mol% Ag_8SiSe_6 exhibit diffraction patterns identical to those of pure orthorhombic Ag_8SiS_6.

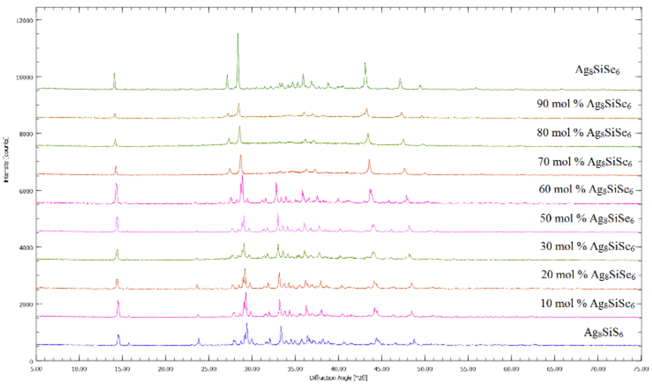

Figure 1
Powder X-ray diffraction patterns of selected alloys in the Ag_8SiS_6–Ag_8SiSe_6 system slowly cooled after annealing

Thus, the results of the presented powder diffraction patterns indicate that, at room temperature, alloys containing 70–90 mol % Ag_8SiSe_6 form cubic-structured phases (δ-phase). The solubility in the RT-Ag_8SiS_6-based phase exceeds 60 mol%, while the solubility in the RT-Ag_8SiSe_6-based phase is below

10 mol%. In Table 1, the powder diffraction patterns of the initial compounds of the Ag_8SiS_6–Ag_8SiSe_6 system and of both series of alloys were indexed using the TOPAS V3.0 software and the lattice parameters were calculated. Figure 2 shows the concentration dependence of the cubic lattice parameter. As can be seen, the lattice parameter of both quenched and slowly cooled samples is a linear function of composition and follows Vegard's law. It should be noted that the lattice parameter values of the samples annealed at 800 K are slightly higher than those of the cubic phases measured at room temperature, which can be explained by the thermal expansion of the lattice upon heating.

Table 1
Crystallographic parameters of phases in the Ag_8SiS_6-Ag_8SiSe_6 system

Composition, mol% Ag_8SiSe_6	Syngony, Sp.Gr., lattice parameters, nm Slowly cooled alloys	Quenched from 800 K alloys
0 (Ag_8SiS_6)	Orthorhombic, (*Pna*2$_1$): *A* = 1.5032(3), *b* = 0.7430(2), *c* = 1.0538(3)	Cubic, ($F\bar{4}3m$): *a* = 1.0635(3)
10	-"-, *a* = 1.5146(4); *b*= 0.749(3); *c* = 1.0627(3)	
20	-"-, *a* = 1.5146(4); *b* = 0.749(3); *c* = 1.0627(3)	-"-, *a* = 1.0824(4)
30	-"-, *a* = 1.5146(4); *b* = 0.749(3); *c* = 1.0627(3)	-"-, *a* = 1.0915(4)
50	-"-, *a* = 1.5146(4); *b* = 0.749(3); *c* = 1.0627(3)	
60	-"-, *a* = 1.5146(4); *b*=0.749(3); *c* = 1.0627(3)	-"-, *a* = 1.1167(4)
70	Cubic, ($F\bar{4}3m$): *a* = 1.077(3)	
80	-"-, *a* = 1.081(4)	-"-, *a* = 1.1344(3)
90	-"-, *a* = 1.085 (4)	
100 (Ag_8SiSe_6)	Cubic, *P*4$_2$32, a = 1.0891(3)	-"-, *a* = 1.0965(3)

On the basis of the DTA data (Table 2), the phase diagram of the system was constructed (Figure 4). As shown, the system exhibits quasi-binary behavior and is characterized by the formation of an extended region of solid solutions (δ-phase) between HT-Ag_8SiS_6 and HT Ag_8SiSe_6. The temperatures along the liquidus and solidus lines vary monotonically between the melting points of the starting compounds.

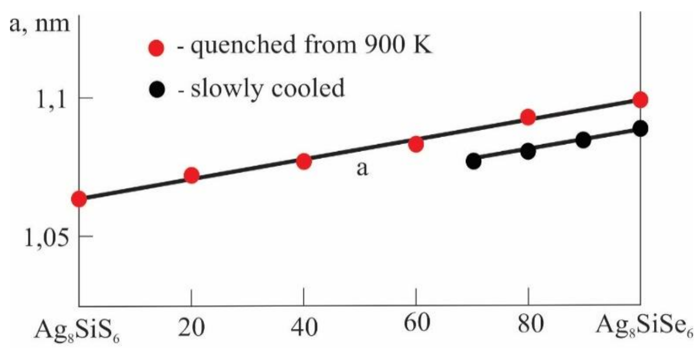

Figure 2
Dependence of the cubic lattice parameter of the Ag_8SiS_6–Ag_8SiSe_6 system on composition

The DTA results show that the polymorphic phase transition characteristic of Ag_8SiS_6 at 513 K shifts toward lower temperatures with Ag_8SiSe_6 content. In alloys containing ≥ 60 mol % Ag_8SiSe_6, no thermal effects are observed on the DTA curves, indicating that the transition occurs below room temperature.

Table 2
The DTA results for the alloys of the Ag_8SiS_6-Ag_8SiSe_6 system

Composition, mol% Ag_8SiSe_6	Thermal effects, K
0 (Ag_8SiS_6)	513; 1225
10	495; 1238
20	467–482; 1232–1238
40	428–443; 1240–1253
50	400–424; 1245–1260
60	360–389; 1249–1262
80	1262–1271
90	1270
100 (Ag_8SiSe_6)	315; 354; 1278

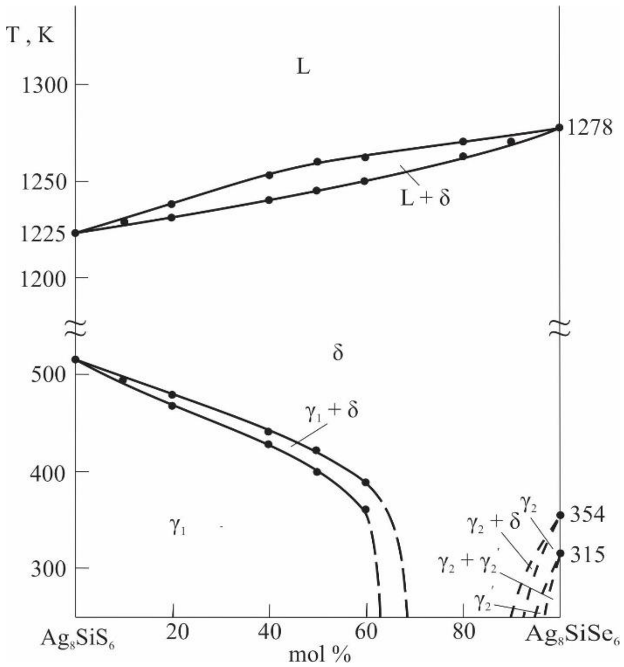

Figure 3
Phase diagram of the Ag_8SiS_6-Ag_8SiSe_6 system

Conclusion

This work presents new data on the phase equilibria in the Ag_8SiS_6–Ag_8SiSe_6 system obtained by differential thermal analysis (DTA) and X-ray diffraction (XRD). Based on the experimental results, the T–x phase diagram of the system was constructed. The system exhibits quasi-binary behavior and forms a continuous series of substitutional solid solutions between the high-temperature modifications of Ag_8SiS_6 and Ag_8SiSe_6. The formation of these solid solutions results in a decrease in the polymorphic transition temperature of Ag_8SiS_6. As a consequence, the ion-conducting cubic phase becomes stabilized at room temperature and even below within the composition range of 70–

90 mol% Ag_8SiSe_6. The lattice parameters of the obtained solid solutions were calculated from powder X-ray diffraction data, and their compositional dependence was found to follow Vegard's law. The newly synthesized solid solutions are promising environmentally friendly materials that exhibit thermoelectric properties along with mixed ionic–electronic conductivity.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 132–138
DOI: https://doi.org/10.36719/2707-1146/65/132-138

Ion Exchange Capacity of Mountain-Forest Soils of the Lankaran Economic Region and its Dependency Patterns

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Abstract. *The Lankaran–Astara region is one of the transitional areas of Azerbaijan's subtropical zone, characterized by complex relief, high precipitation, and rich forest cover. These natural factors lead to the intensive development of complex geochemical processes in the soil profile, including ion-exchange reactions. The article provides detailed information on the cation exchange capacity (CEC) and anion exchange capacity (AEC) of mountain-forest soils in the region and analyzes their dependence on soil texture, mineralogical composition, organic matter content, and soil reaction (pH). The research results showed that the CEC of soils in the region ranges from 12.5 to 35.8 cmol/kg, while the AEC varies between 150 and 450 mg/kg. The ion-exchange properties differ significantly across altitudinal zones, reflecting the diversity of soil formation processes in the region.*

Keywords: *cation exchange capacity, anion exchange capacity, mountain-forest soils, Lankaran–Astara region, pH, humus, clay minerals*

Introduction

One of the most fundamental indicators determining the genetic characteristics, ecological functions, and agro-production potential of soil cover is its ion-exchange capacity. At the same time, the ion-exchange capacity of soils defines their buffering properties, i.e., their resistance to external impacts such as acid rain, fertilization, and pollution (Sposito, 2008).

In the scientific literature, cation exchange capacity (CEC) and anion exchange capacity (AEC) are considered among the most important indicators characterizing both the agrochemical potential of soils and their buffering capacity against various natural and anthropogenic pollutants (Babayev et al., 2017). Recent studies have emphasized that CEC serves as a fundamental parameter for assessing soil quality and ecosystem resilience, particularly in forest ecosystems where nutrient retention capacity directly influences vegetation productivity (Coppola & Mollo, 2019). CEC refers to the ability of negatively charged soil surfaces to retain positively charged ions. This capacity is mainly formed due to permanent charges arising from isomorphic substitution in the structure of clay minerals, as well as pH-dependent charges resulting from the dissociation of functional groups (carboxyl, phenolic, alcoholic) in organic matter (Tan, 1998). AEC, on the other hand, is the ability of positively charged soil surfaces to retain negatively charged ions and is mainly formed due to the protonation of iron, aluminum, and manganese oxides and hydroxides, as well as certain functional groups (amino groups) of organic matter (Khidirov, 2010).

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Received: 13 January 2026; Accepted: 20 March 2026; Published online: 25 April 2026

Both cation and anion exchange capacities are key indicators of soil fertility, ecological stability, and suitability for agricultural use (Guliyev, 2018). It is observed that minerals of the kaolinite group dominate in the mineralogical composition of the region’s soils, along with the presence of hydromicas, vermiculite, and chlorite in certain amounts (Mammadov, 2002). The combination of these clay minerals creates a complex exchange complex where kaolinite contributes to low permanent charge while 2:1 minerals (vermiculite, hydromica) enhance overall CEC values, a pattern commonly observed in subtropical forest soils with mixed mineralogy (Bhattacharyya et al., 2020).

Although kaolinite has a relatively low CEC (2–15 cmol/kg), the presence of 2:1 type clay minerals (hydromicas, vermiculite, smectite) contributes to an increase in CEC. Expanding clay minerals such as vermiculite and smectite have high CEC (80–150 cmol/kg), and as their content increases, the overall CEC of the soil significantly rises (Bradl, 2004). In addition, under humid subtropical climate conditions, the accumulation of iron and aluminum oxides and hydroxides (sesquioxides) plays an important role in the formation of anion adsorption capacity. Minerals such as goethite, hematite, and gibbsite become positively charged in acidic environments, leading to the fixation of phosphates, sulfates, and other anions in the soil (Ismayilov, 2012).

The study of ion-exchange properties of soils is important not only from a theoretical perspective but also has great practical significance. Based on these indicators, fertilization rates are determined, liming of acidic soils is carried out, reclamation measures are planned, and the ecological stability of soils is assessed and monitored (Gahramanov, 2015). In the Lankaran–Astara region, the intensive development of agricultural sectors such as tea cultivation, citrus growing, and vegetable production makes the efficient use of soils, as well as the preservation and enhancement of their fertility, particularly relevant.

Materials and Methods

The object of the study is the mountain-forest soils distributed in the Lankaran–Astara region. The study area is located on the northeastern slopes of the Talysh Mountains, at elevations ranging from 0 to 1600 m above sea level. The research was conducted during 2023–2025. Soil profile excavation and description were carried out according to generally accepted methodologies. Soil profiles were grouped by elevation zones and soil types as follows: in the lower mountain belt (0–400 m) — yellow soils; in the middle mountain belt (400–1000 m) — podzolized yellow soils and mountain brown forest soils; and in the upper mountain belt (1000–1600 m) — mountain brown forest soils.

Soil profiles were established under typical vegetation cover characteristic of each soil type and across different elements of the relief (upper, middle, and lower parts of slopes). Morphological descriptions were conducted for each soil profile, and genetic horizons were identified: A_0 (forest litter), A_1 (humus accumulation), A_2 (eluvial), B (illuvial), and C (parent material). Soil color was determined using the Munsell color chart (Munsell Color Company, 2000).

Soil samples were collected from each genetic horizon at intervals of 10–20 cm depending on horizon thickness, with an average sample weight of 1–1.5 kg. Samples were placed in polyethylene bags, labeled, and transported to the laboratory. In total, 46 soil samples were collected. In the laboratory, soil samples were air-dried, cleaned of coarse fragments and root residues, crushed using a wooden pestle, and sieved through a 2 mm sieve. Representative samples were prepared for analysis. For the determination of organic matter content, separate samples were sieved through a 0.25 mm sieve (Van Reeuwijk, 2002).

Soil texture was determined using the pipette method according to N. A. Kachinsky (1958). Soil particles were divided into the following fractions: physical sand (>0.01 mm) and physical clay

(<0.01 mm). Additionally, fine fractions (<0.001 mm, 0.001–0.005 mm, 0.005–0.01 mm) were also determined.

Organic matter content was determined by the Tyurin method in the Gustavson modification (Arinushkina, 1970), based on the oxidation of organic carbon with potassium dichromate. Humus content was calculated by multiplying the organic carbon content by a factor of 1.724. Soil pH was measured potentiometrically (ISRIC, 2002) in both water and 1N KCl solution, using a soil-to-solution ratio of 1:2.5. Measurements were carried out using a pH meter (HANNA Instruments HI 2211).

Two methods were used to determine cation exchange capacity (CEC) (Gedroiz, 1955):
- For neutral and alkaline soils: saturation with 1N CH_3COONa solution at pH 7.0. The soil was saturated with sodium acetate, and the absorbed sodium was determined using a flame photometer.
- For acidic soils: saturation with 1N CH_3COONH_4 solution at pH 7.0. The absorbed ammonium was determined by distillation using a Kjeldahl apparatus.

Phosphate adsorption capacity was determined using the Blomback-Maclaurin method (Blomback & Maclaurin, 1956). Soil samples were mixed with KH_2PO_4 solution, and phosphorus concentration in the equilibrium solution was measured colorimetrically using the Murphy–Riley method. The amount of adsorbed phosphorus was calculated as the difference between initial and equilibrium phosphorus concentrations.

Total anion exchange capacity was determined using the Mehlich method (extraction with 1N NH_4Cl solution) (Mehlich, 1984; Sparks et al., 1996). Exchangeable calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined by complexometric methods, while exchangeable potassium (K^+) and sodium (Na^+) were measured using a flame photometer (PAJ-2 model). The amounts of hydrogen and aluminum were determined using the Gedroiz method.

Results and Discussion

According to the research results, the cation exchange capacity (CEC) of mountain-forest soils in the Lankaran–Astara region varies between 11.5 and 32.5 cmol/kg (Table 1). The highest CEC values are observed in the upper humus horizons (A_1), which is associated with the high organic matter content (5.2–7.5%).

Table 1
Physicochemical properties of mountain-forest soils in the Lankaran region

Soil type	Elevation, (m)	Horizon	Depth (cm)	Humus	Physical clay (%)	CEC cmol/kg	AEC mg/kg
Yellow soils	0–400	A_1	0–15	5.2 ± 0.8	42.5 ± 3.8	18.5 ± 2.1	425 ± 35
		B	15–45	2.1 ± 0.4	48.3 ± 4.2	22.3 ± 2.5	445 ± 40
		C	45–80	0.8 ± 0.2	35.6 ± 3.5	12.4 ± 1.8	385 ± 30
Podzolized yellow soils	400–800	A_1	0–18	6.8 ± 0.9	38.7 ± 3.6	24.6 ± 2.8	315 ± 28
		A_2	18–35	1.8 ± 0.3	28.5 ± 3.0	14.2 ± 1.9	285 ± 25
		B	35–65	1.2 ± 0.3	45.2 ± 4.0	26.8 ± 2.9	355 ± 32
		C	65–95	0.5 ± 0.1	32.4 ± 3.2	11.5 ± 1.6	295 ± 26

Mountain brown forest soils	800–1300	A_1	0–20	6.2 ± 0.8	35.8 ± 3.4	28.5 ± 3.1	245 ± 22
		B	20–50	2.5 ± 0.4	40.5 ± 3.7	26.2 ± 2.8	265 ± 24
		C	50–85	1.1 ± 0.2	30.2 ± 3.1	14.8 ± 1.9	185 ± 18
Mountain brown forest soils (upper belt)	1300–1600	A_1	0–15	7.5 ± 1.0	32.5 ± 3.3	32.5 ± 3.5	195 ± 20
		B	15–45	2.8 ± 0.5	38.2 ± 3.5	28.5 ± 3.0	215 ± 22
		C	45–80	1.2 ± 0.3	28.5 ± 2.9	15.5 ± 1.8	155 ± 16

Along the soil profile, CEC decreases with increasing depth: in yellow soils, it is 18.5 cmol/kg in the A_1 horizon and 12.4 cmol/kg in the C horizon; in mountain brown forest soils (upper belt), it is 32.5 cmol/kg in the A_1 horizon and 15.5 cmol/kg in the C horizon. In podzolized yellow soils, the relatively high CEC in the B horizon (26.8 cmol/kg) is explained by the illuvial accumulation of clay minerals (2:1 type). This vertical distribution pattern of CEC is characteristic of mountain forest ecosystems, where organic matter accumulation in surface horizons and clay translocation to deeper layers jointly control the exchange complex (Pinto et al., 2021).

The study of the mineralogical composition showed that kaolinite predominates in the clay fraction of the region's soils, while hydromicas, vermiculite, and chlorite are also present in certain amounts (Table 2). In particular, the relatively higher content of 2:1 type clay minerals (hydromicas, vermiculite) in the B horizons contributes to maintaining CEC at a certain level.

Table 2
Mineralogical composition of soils (clay fraction, %)

Soil type	Horizon	Kaolinite %	Hydromica (%)	Vermiculite %	Chlorite %	Quartz %	Iron oxides %
Yellow soils	A_1	45–50	15–20	5–8	3–5	10–15	8–12
	B	40–45	18–22	6–10	4–6	8–12	10–15
Podzolized yellow soils	A_1	48–52	12–16	4–6	2–4	12–16	6–10
	B	42–46	16–20	8–12	5–8	8–12	10–14
Brown forest soils	A_1	35–40	22–26	10–14	6–8	10–14	4–6
	B	32–36	24–28	12–16	8–10	8–12	5–8

The analysis of mineralogical composition indicates that the content of hydromica and vermiculite is higher in mountain brown forest soils compared to yellow soils. This is one of the reasons for the higher CEC values observed in these soils. Although kaolinite has a relatively low CEC (2–15 cmol/kg), the presence of 2:1 type clay minerals contributes to an increase in overall CEC.

Table 3
Changes in anion exchange capacity (AEC) at different pH values (mg/kg)

Soil type	AEC at pH 4.0	AEC at pH 5.0	AEC at pH 6.0	AEC at pH 7.0
Yellow soils	485 ± 42	425 ± 38	345 ± 32	255 ± 28

Podzolized yellow soils	395 ± 35	335 ± 30	275 ± 26	205 ± 22
Mountain brown forest soils	285 ± 26	245 ± 24	195 ± 20	145 ± 16

The study of AEC at different pH values further confirms this relationship (Table 3). In all soil types, as pH increases from 4.0 to 7.0, AEC decreases approximately twofold. The most pronounced decrease is observed in yellow soils (from 485 mg/kg to 255 mg/kg). This strong pH dependence of AEC is attributed to the variable charge characteristics of iron and aluminum oxides (sesquioxides), which dominate the exchange complex in highly weathered subtropical soils. At low pH, protonation of these oxide surfaces creates positive charges capable of retaining anions, while increasing pH promotes deprotonation and subsequent reduction in anion retention capacity (Gomes et al., 2022).

Table 4

Dependence of CEC and AEC on soil texture

Texture class	Physical clay (<0.01 mm, %)	CEC (cmol/kg)	AEC (mg/kg)
Sandy	<10	8.5 ± 1.2	185 ± 22
Sandy loam	10–20	14.2 ± 1.8	245 ± 28
Loam	20–30	20.5 ± 2.4	295 ± 32
Clay loam	30–40	26.8 ± 3.0	335 ± 35
Clay	>40	32.5 ± 3.5	385 ± 40

A strong relationship was established between soil texture and ion-exchange capacity. The results show that as the proportion of the physical clay fraction increases, both CEC and AEC increase consistently (Table 4).

Table 5

Comparison of ion-exchange properties across elevation belts

Indicators	Lower belt (0–400 m)	Middle belt (400–1000 m)	Upper belt (1000–1600 m)
CEC (cmol/kg)	18.5 ± 2.1	26.5 ± 3.2	32.5 ± 3.5
AEC (mg/kg)	425 ± 35	280 ± 30	195 ± 20
Humus (%)	5.2 ± 0.8	6.5 ± 0.9	7.5 ± 1.0
pH	4.8 ± 0.2	5.1 ± 0.3	5.8 ± 0.3
Ca^{2+} (cmol/kg)	10.2 ± 1.2	14.5 ± 1.6	16.5 ± 1.8
Base saturation (%)	72.5 ± 4.5	78.5 ± 5.0	88.5 ± 5.2
Fe_2O_3 (%)	8.5 ± 1.2	6.2 ± 0.9	4.5 ± 0.7

Significant differences in ion-exchange properties are observed across elevation belts (Table 5). With increasing altitude, CEC, humus content, pH, and base saturation increase, whereas AEC and iron oxide content decrease.

Conclusion

The study revealed that the ion-exchange properties of mountain-forest soils in the Lankaran–Astara region follow the patterns of vertical zonation. The cation exchange capacity (CEC) ranges from 11.5 to 32.5 cmol/kg. The highest value (32.5 cmol/kg) was recorded in the upper mountain belt (1300–

1600 m), in the humus horizon of mountain brown forest soils, which is associated with high humus content (7.5%) and the dominance of 2:1 clay minerals (illite and vermiculite). In the lower belt (0–400 m), yellow soils show lower CEC values (18.5 cmol/kg), where kaolinite prevails. The anion exchange capacity (AEC) varies between 155 and 445 mg/kg. The maximum value (445 mg/kg) is observed in the B horizon of yellow soils, which is related to the high content of iron oxides (10–15%). An inverse relationship exists between AEC and pH: at pH 4.0, AEC is 485 mg/kg, while at pH 7.0 it decreases to 255 mg/kg. As the content of the physical clay fraction increases, both CEC and AEC also increase. In heavy clay soils (>40% physical clay), CEC reaches 32.5 cmol/kg, while AEC is 385 mg/kg. With increasing altitude, CEC (from 18.5 to 32.5 cmol/kg), humus content (from 5.2% to 7.5%), pH (from 4.8 to 5.8), and base saturation (from 72.5% to 88.5%) increase, whereas AEC decreases (from 425 to 195 mg/kg). The study of the ion-exchange properties of soils in the region is of great importance for assessing their fertility potential, optimizing fertilization systems, and planning meliorative measures.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 139–144
DOI: https://doi.org/10.36719/2707-1146/65/139-144

Approaches and Principles for the Restoration of Tugay Forests in Azerbaijan

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Abstract. *Tugay (riparian) forests are among the rarest and most functionally important ecosystems in Azerbaijan's arid and semi-arid lowlands. They provide bank stabilization, microclimate regulation, habitat connectivity, and biodiversity support along the Kura and Araz river corridors. Yet tugay forests have been strongly degraded and fragmented by hydrological regulation, reduced floodplain inundation, groundwater decline, grazing pressure, land conversion, and technogenic impacts. Restoration in this context cannot be treated as ordinary afforestation; it requires re-establishing the coupled river–floodplain–groundwater processes that sustain recruitment and long-term stand persistence. This paper synthesizes national ecosystem assessment findings, official reporting, and peer-reviewed restoration ecology frameworks to produce a restoration framework tailored to Azerbaijan. The core proposition is a driver-based restoration logic linking pressures to geomorphic and hydrological processes, expected ecological responses, measurable indicators, and priority interventions. The paper emphasizes environmental flows, floodplain connectivity, protected-area anchors, and adaptive monitoring supported by remote sensing and field inventories. A set of restoration principles and an intervention sequence are proposed for implementation under realistic constraints, with success criteria aligned to internationally recognized ecological standards and adaptive governance principles.*

Keywords: *tugay forests, riparian restoration, Kura River, Araz River, environmental flows, floodplain connectivity, groundwater, protected areas, adaptive management, Azerbaijan*

Introduction

Tugay forests (also spelled "tugai") are riparian forest ecosystems in arid and semi-arid river valleys whose structure and regeneration are strongly dependent on river flow regimes, sediment dynamics, and shallow groundwater availability. In continental desert regions, tugay systems form linear corridors of floodplain forests and shrublands that create biodiversity "islands" in otherwise steppe or semi-desert landscapes. The ecological significance of tugay forests derives from their role as habitat, migration corridors, bank-stabilizing vegetation, and microclimate moderators.

In Azerbaijan, riparian forests occupy mainly floodplains and banks of the Kura and Araz rivers, where groundwater can remain within reach of deep-rooted phreatophytes under natural or semi-natural conditions. However, regulation of flows, water withdrawals, floodplain fragmentation, and land conversion have reduced the frequency and duration of overbank flooding, limited sediment deposition, and lowered groundwater recharge.

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Received: 11 January 2026; Accepted: 16 March 2026; Published online: 25 April 2026

These changes disrupt the recruitment of floodplain trees and the persistence of multi-layered riparian communities. National policy and reporting documents also provide a baseline for restoration relevance within broader land-use and climate frameworks. Official reports include forest restoration and planting activities, and identify the restoration and reconstruction of tugay forests as a direction of work in the Kura and Araz valleys (Republic of Azerbaijan, 2015). More recent climate reporting continues to frame forest expansion within mitigation commitments (Republic of Azerbaijan, 2023). The national ecosystem assessment provides additional ecosystem-service context and explicitly describes tugay forests as dependent on shallow groundwater and floodplain space, with flow regulation identified as a mechanism reducing floodplain extent and degrading tugay systems (Azerbaijan National Ecosystem Assessment, 2024).

Protected-area leverage is a practical entry point for tugay restoration because it concentrates governance tools (restrictions, monitoring, enforcement) and provides a spatial anchor for ecological recovery. In Azerbaijan, protected areas such as the Garayazi/Qarayazi State Nature Reserve protect remnant tugay fragments and can serve as restoration nuclei (Administrative Department of the President of the Republic of Azerbaijan—Presidential Library, n.d.).

This paper develops a restoration-oriented synthesis for tugay forests in Azerbaijan that is intended to be implementable under real constraints: regulated flows, competing land and water demands, and climate aridification risks. The objective is not to restate generic riparian restoration guidance, but to translate evidence into a driver-based prioritization logic, measurable success criteria, and an adaptive intervention sequence suitable for the Kura–Araz lowlands and associated protected tugay fragments. (Beechie et al., 2010; Palmer et al., 2005; Pahl-Wostl et al., 2012).

Methods

This study is a synthesis-and-framework paper that combines (i) official national reporting and ecosystem assessment documents, (ii) peer-reviewed riparian and restoration ecology literature (prioritizing Scopus-indexed sources with DOI records where available), and (iii) the reference list extracted from the source manuscript provided by the author (see Appendix mapping table). The analytical method follows a driver → process → response → intervention chain, which is consistent with widely used restoration planning logic (e.g., linking stressors to mechanisms and then to actions and monitoring) (Beechie et al., 2010; Hobbs & Harris, 2001).

Hydrological and ecological reasoning is anchored in the "natural flow regime" paradigm and the environmental flow literature, emphasizing that variability in magnitude, timing, frequency, duration, and rate of change of flows underpins river–floodplain ecosystem integrity (Poff et al., 1997). In tugay contexts, these flow attributes translate into floodplain inundation opportunities, groundwater recharge, and sediment disturbance regimes needed for recruitment and vegetation succession.

The paper also integrates principles from riparian zone ecology, emphasizing that riparian corridors are land–water interfaces where ecological processes are shaped by both watershed-scale drivers and local floodplain conditions (Gregory et al., 1991; Naiman & Décamps, 1997).

Remote sensing is treated as a complementary monitoring tool rather than a stand-alone assessment method. Evidence from high-resolution imagery analysis of tugay vegetation in Central Asia demonstrates the value of object-based change detection for identifying vegetation dynamics and monitoring restoration outcomes, particularly when coupled with field verification (Gärtner et al., 2014).

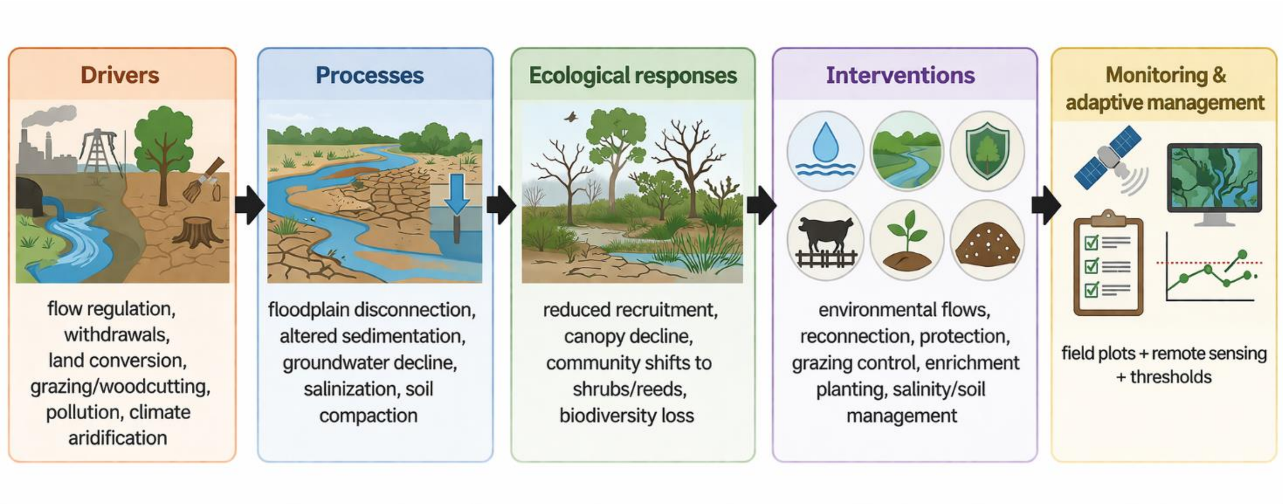

Figure 1
Conceptual framework of ecosystem processes and adaptive management

Results

National-level sources indicate that Azerbaijan's forests are not evenly distributed: they are concentrated in mountain regions but also occur along the lower Kura and Araz as a belt, and restoration/reconstruction of tugay forests in these valleys has been identified as an ongoing direction of work. Reported figures in national communication include forest area estimates and annual restoration/planting activities (Republic of Azerbaijan, 2015). In the most recent ecosystem assessment synthesis reviewed here, tugay forests are explicitly characterized as dependent on shallow groundwater and floodplain space, with flow regulation in the Kura identified as a mechanism shrinking floodplain area and stressing tugay systems (Azerbaijan National Ecosystem Assessment, 2024).

Table 1
Driver groups affecting tugay forests and restoration implications

Driver group	Typical pressures in Azerbaijan tugay contexts	Dominant processes	Expected ecological response	Practical indicators	Priority interventions
Hydrological regulation and withdrawals	Reservoir operations, irrigation abstraction, reduced overbank flooding	Reduced floodplain inundation; lowered groundwater recharge; altered sediment regime	Recruitment failure; canopy thinning; compositional shifts	Inundation frequency; groundwater depth/salinity; seedling density	Environmental flow thresholds; floodplain reconnection; groundwater-sensitive site selection
Land conversion and fragmentation	Floodplain agriculture, infrastructure, channel constraint	Loss of floodplain area; disconnection of side channels	Reduced habitat continuity; simplified structure	Floodplain width; corridor continuity	Spatial zoning; buffer enforcement; targeted corridor restoration
Grazing and woodcutting pressure	Livestock browsing, fuelwood harvest, understory disturbance	Reduced regeneration; soil compaction	Seedling suppression; erosion	Browsing intensity; grazing pressure	Controlled grazing regimes;

Driver group	Typical pressures in Azerbaijan tugay contexts	Dominant processes	Expected ecological response	Practical indicators	Priority interventions
				indices; regeneration rates	enforcement; alternative fuel programs
Invasive species and disturbance	Colonization by non-native taxa; disturbance-mediated spread	Competitive displacement; altered succession	Reduced native diversity	Invasive cover; species composition metrics	Early detection/rapid response; mechanical removal; replanting native guilds
Climate aridification and heat stress	Increased drought frequency; higher evapotranspiration	Increased water stress; reduced growth	Mortality during drought; decline in vigor	Drought indices; canopy condition	Drought-resilient species selection; hydrological buffering; adaptive monitoring
Pollution and technogenic pressure	Industrial/agricultural runoff; localized contamination	Toxic stress; reduced soil/leaf function	Reduced vigor; decline in sensitive species	Water/soil contaminants; leaf condition	Source control; riparian buffers; targeted remediation

This driver structuring is consistent with the causal mechanisms emphasized by riparian ecology: flow and groundwater regimes are first-order controls on riparian vegetation composition and recruitment, and human modifications can propagate through multiple pathways (Allan, 2004; Naiman & Décamps, 1997; Merritt et al., 2010). Moreover, national syntheses specific to Azerbaijan explicitly link shallow groundwater, floodplain space, and flow regulation to tugay condition (Azerbaijan National Ecosystem Assessment, 2024).

A key operational implication of the driver analysis is that tugay restoration in Azerbaijan should be treated as a flow–groundwater–land-use coupled problem rather than a tree-planting problem. Where floodplain area is reduced and groundwater declines, planting without hydrological correction is likely to produce short-lived stands or repeated failures. Empirical work in arid tugay analogues demonstrates strong relationships between groundwater depth/salinity, soil conditions, and tugay species diversity and distribution, reinforcing the need for threshold-based site selection and water management integration (Zeng et al., 2020).

Restoration prioritization can be strengthened by explicitly incorporating environmental thresholds into water-withdrawal decisions in tributaries and headwaters that affect downstream tugay forests. For Azerbaijan's Kura basin, peer-reviewed work has proposed environmentally relevant limits for exploitation of mountain streams, which is directly aligned with a downstream tugay protection logic when combined with floodplain management (Abbasov & Smakhtin, 2009).

Protected-area anchors are practically important because they support enforcement and reduce competing land-use pressures. Official guidance describing protected area categories in Azerbaijan indicates how sanctuaries/reserves function as conservation instruments, which can be operationalized to protect tugay fragments and support restoration nuclei (Administrative Department of the President of the Republic of Azerbaijan—Presidential Library, n.d.; Azerbaijan National Ecosystem Assessment, 2024).

Monitoring and adaptive management should integrate remote sensing with repeated field inventories. Local studies along the Kura River in the Agjabadi district illustrate how phytocoenological characterization can inform the selection of restoration diagnostics and indicators (Gurbanov & Ahmadova, 2024). Combining such local field approaches with remote sensing change detection creates a defensible monitoring system for decision cycles. (Gurbanov & Ahmadova, 2024; Gärtner et al., 2014).

Implications for national policy alignment

Official reporting indicates that Azerbaijan has ongoing forest restoration activities and that tugay restoration in the Kura and Araz valleys is an explicit direction of work, while recent climate reporting frames forest expansion and sequestration within national commitments. Tugay restoration can therefore be positioned as both adaptation (ecosystem resilience, bank stabilization, microclimate buffering) and mitigation (carbon storage within riparian corridors), but only if hydrological constraints are addressed and success is measured transparently (Republic of Azerbaijan, 2015; Republic of Azerbaijan, 2023).

Conclusion

Tugay forest restoration in Azerbaijan should be defined as the recovery of a hydrologically connected floodplain forest system, not merely the re-establishment of tree cover. The evidence supports a basin–landscape restoration strategy built around (i) environmental flow and groundwater thresholds, (ii) protected-area anchors (especially Garayazi/Qarayazi), (iii) integrated land-use controls and grazing/woodcutting management, and (iv) adaptive monitoring that blends repeated field inventories with high-resolution remote sensing. This approach aligns national ecosystem assessment findings—highlighting the dependence of riparian forests on shallow groundwater and the negative effects of flow regulation—with international standards for ecologically successful river restoration and integrated governance under climate uncertainty.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 145–152
DOI: https://doi.org/10.36719/2707-1146/65/145-152

Mammalian Species Successfully Introduced to Azerbaijan: Biology and Adaptive Traits

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Abstract. *Introduction processes carried out in Azerbaijan have been implemented with the aim of enriching the biodiversity of our country, serving economic interests, and controlling other harmful rodent species. However, the lack of in-depth scientific research has led both to the introduction of harmful species and to the extinction of some introduced species. As a result, out of ten introduced mammal species, only three species have survived. The surviving species include the European rabbit, the raccoon, and the nutria. Due to the highly developed adaptive characteristics of these successfully acclimatized species, each of them has expanded its range. However, the excessive increase in the populations of these species, while serving economic interests, has also led them to play a harmful role in various aspects. This, in turn, results in noticeable changes within the ecosystem. Therefore, it is highly important that future introduction processes be carried out on a purposeful basis and grounded in thorough scientific research.*

Keywords: *european rabbit, nutria, raccoon, Azerbaijan, acclimatization*

Introduction

Between 1930 and 1970, a number of mammal species were acclimatized in Azerbaijan under various rationales and under the slogan of “enrichment and reconstruction of the fauna of Azerbaijan”. Most introductions were undertaken to meet hunting demands or to ensure economically profitable fur production; in some cases, they were motivated by pharmaceutical needs or by the necessity to control rodents that were epidemiologically hazardous or harmful to agriculture (Askerov et al., 2021).

Throughout the history of acclimatization, both in the former USSR and in Azerbaijan, zoologists and game specialists have included both proponents and opponents of species introductions. In characterizing half a century of experience in introduction practices, the following statement by A.A. Nasimovich, one of the leading experts on this issue, is particularly relevant: “Until recently, the acclimatization of animals in our country was initiated by various agencies and, at times, by individual persons. This work was conducted without a unified, coordinated plan and without full consideration of the overall interests of the national economy. Empiricism predominated. Until the early 1960s, the acclimatization of fur-bearing animals was frequently regarded as a universal solution to all problems in game management. Excessive reliance on this approach led to an underestimation of the importance of work with native species, and comprehensive breeding measures were replaced by introductions”.

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Received: 4 January 2026; Accepted: 28 March 2026; Published online: 25 April 2026

The aforementioned shortcomings were also observed in our republic. There is no doubt that the establishment of new species leads, to varying degrees, to the restructuring of cenotic relationships, changes in the volume of ecological niches of native species, shifts in the ecology of introduced species, and, in certain cases, to alterations in the overall structure of communities. Consequently, under new environmental conditions, a species that is beneficial or neutral in its native range may become harmful (Vereshchagin, 1958).

In total, ten mammal species (*Myocastor coypus* M. – nutria, *Chinchilla brevicauda* W. – short-tailed chinchilla, *Nyctereutes procyonoides* G. – raccoon dog, *Procyon lotor* L. – raccoon, *Mephitis mephitis* S. – striped skunk, *Mustela vison* S. – American mink, *Cervus nippon* T. – sika deer, *Saiga tatarica* L. – saiga antelope and *Bison bonasus* L. – European bison, *Oryctolagus cuniculus* L. – European rabbit) were introduced into the republic. Successful acclimatization was achieved only for the European rabbit, nutria, and raccoon. In addition, some released species survived in the natural environment of the republic for a certain period and even reproduced until they were eliminated by predators or by competition with native fauna. Their skeletal remains have persisted in the soil in various forms. There are documented cases of bones of introduced mammals being discovered during soil excavation works, as well as in the pellets of diurnal and nocturnal birds of prey (Vereshchagin, 1959; Vereshchagin, 1951; Vereshchagin, 1952).

The general biology of European rabbit (*O. cuniculus* L.)

The European rabbit belongs to the order Lagomorpha, the family Leporidae, and the genus Oryctolagus (Ahmadov et al., 2023).

Its natural range includes the European and African parts of the Mediterranean region, as well as the southern part of North America, Central, and South America. Additionally, in the 19th century, it was introduced to southern Ukraine, many regions of Australia, New Zealand, and Oceania, as well as to numerous islands and sub-Antarctic zones (Rossolimo et al., 2004; Sokolov, 1989). The population of European rabbits introduced to Robben Island, recognized by UNESCO as a World Heritage Site, remained relatively stable from October 2003 to November 2005 (Villiers et al., 2010).

Its body length ranges from 31 to 45 cm, and its weight is 1.3–2.5 kg, with ears and hind limbs measuring 6–7.2 cm. The fur is soft and dense, consisting of short, straight hairs. The dorsal side is gray-brown, while the ventral side is white. The underside of the tail is white, and the upper side is either darkened or matches the color of the back. The ears are short, rounded at the tips, and black in color. The species molts twice a year, and it takes approximately 1.5 months for new fur to grow. In males, fur development occurs later compared to females (Rossolimo et al., 2004; Ahmadov et al., 2023; Sokolov, 1989). In some populations, melanistic individuals are frequently observed (Aulagnier et al., 2009).

They prefer areas with soft soils, valleys, hilly terrain, and shrub-covered landscapes, as well as small forests. They are not afraid of human presence and can also inhabit gardens and parks. European rabbits can dig burrows more easily in sandy soils compared to clayey or stony soils (Rossolimo et al., 2004; Ahmadov et al., 2023). Since European rabbits are not well adapted to persistently snowy winter conditions, their need to dig burrows is significant (Sokolov, 1989). They live in family groups connected by a network of communal burrows. The burrows have multiple entrances and exits, with a total length that can reach up to 40 meters, consisting of interconnected tunnels at various angles. Each burrow contains several nesting chambers located along the main tunnel. The floors of these chambers are either bare or lined with rabbit fur. A single burrow may be used for several years, and its territory can cover 0.5–20 hectares. The territories of different groups overlap minimally. The area is usually defended by the dominant male. The dominant female in the group lives in the communal burrow with this male and their offspring, while other females occupy separate burrows. For each new litter, a female typically digs a separate nesting chamber. During digging, she collects soil under her body with her forelegs and then throws it out with her hind legs. Each family group consists of 1–8 males and 1–12 females. Aggressive interactions are more commonly observed between females. European rabbits lead a sedentary lifestyle and rarely leave their burrows. This behavior allows them to hide quickly from danger but also limits their feeding area (Rossolimo et al., 2004; Ahmadov et al., 2023).

European rabbits rarely move more than 100 meters from their burrows to feed. Their diet consists of leaves and stems of grasses, cabbage in fields and gardens, various root crops and cereal plants, dry herbs, as well as the underground parts of plants (Ahmadov et al., 2023). During summer, their main food is grasses, while in winter they consume dry herbs, seeds, roots of various plants, young shoots, and the bark of shrubs and trees (Rossolimo et al., 2004). When no other food is available, they do not refrain from eating their own feces (coprophagy) (Ahmadov et al., 2023). This behavior, called coprophagy, enables the assimilation of essential vitamins, improves the digestion of plant-based food, and allows the reabsorption of water into the body (Fortanesi et al., 2021).

Most European rabbits are polygamous, though some are monogamous and live with a specific female. The mating season begins in February. Mating occurs synchronously, with almost all females entering estrus at the same time. The gestation period lasts 28–32 days. A female can mate a few hours after giving birth and may produce a litter every 5–8 weeks. Litter sizes range from 2 to 12 offspring. The number of litters per year depends on food availability and the reproductive activity of males. In Europe, a female can produce up to 5 litters per season; in mountainous regions, 2–4; and in lowland areas, 3–5. Newborn rabbits are hairless and blind, weighing 37–54 grams. By three days old, their bodies are covered with short fur; they open their eyes around 10 days, and by three weeks, their full coat develops. At 25 days, the young begin to live independently. Sexual maturity is reached at 5–6 months, allowing participation in reproduction. A small proportion live up to 3 years, while the maximum lifespan is 12–15 years (Rossolimo et al., 2004; Ahmadov et al., 2023; Aulagnier et al., 2009). Juvenile mortality is high, especially during rainy conditions when nests become wet or flooded. Approximately 40% of young die within the first three weeks, with many succumbing to coccidiosis (Sokolov, 1989).

European rabbits remain active throughout the year and do not hibernate during winter (Ahmadov et al., 2023). They can be active both during the day and at night (Rossolimo et al., 2004). In anthropogenic habitats and during the winter season, they adopt a primarily nocturnal lifestyle. Chemical communication (chemo-communication) is well developed in European rabbits, allowing them to convey information about their sex, age, and social status through scent. Quasi-acoustic signals, produced by striking the ground with their paws, have also been observed. They run slowly but are very agile, making it difficult to catch an adult rabbit on the ground (Ahmadov et al., 2023). Over short distances, they can move at speeds of 20–25 km/h (Sokolov, 1989).

The density of European rabbit habitats and the conservatism of their burrow selection make them vulnerable to natural infections and epizootics. One of the main methods of human control over rabbits has been the deliberate spread of infections into their habitats. Introducing rabbits to new areas is sometimes accompanied by rapid population growth, most notably observed in Australia and New Zealand. In such cases, rabbits can completely destroy pasture vegetation, displacing native herbivorous mammals (Rossolimo et al., 2004). Predators previously absent from these regions—such as foxes, martens, piglets, and weasels—were introduced, but these measures were largely ineffective, and rabbits continued to reproduce (Sokolov, 1989). Highly virulent rabbit hemorrhagic disease virus (RHDV) has been widely used in Australia and New Zealand to reduce rabbit populations (Mahar et al., 2018). In the early 1950s, Australian settlers launched a “bacteriological war” by infecting rabbits with the virus causing myxomatosis. This disease does not affect humans, domestic animals, or many wild species. The initial results were dramatic: up to 90% of rabbits in many regions of Australia were eliminated. However, by the 1960s, rabbit numbers rebounded because some individuals had inherited immunity to myxomatosis or gradually developed resistance (Sokolov, 1989). Myxomatosis was also used on Kerguelen Island but proved ineffective (Cooper & Brooke, 1982). Currently, the "rabbit problem" in Australia is less severe, as demand for rabbit meat has increased, and it has even become a product for export and trade (Sokolov, 1989; Rossolimo et al., 2004).

Introduction of the European rabbit in Azerbaijan (*O. cuniculus* L.)

Within the genus *Oryctolagus*, only a single species exists. The European wild rabbit (*O. cuniculus*) is the only lagomorph species that has been domesticated and has given rise to numerous breeds (Sokolov, 1989). This is the only species acclimatized in Azerbaijan without the participation of zoologists. According to N. K. Vereshchagin, at the end of the 19th century, migrant fishermen released domestic European rabbits on Sara Island near Lankaran. This attempt was unsuccessful, and the animals failed to survive there. Later in the same century, following the establishment of regular shipping routes and the development of fisheries, lighthouse keepers released these rabbits on several islands of the Baku and Absheron archipelagos (Boyuk Zira, Khara Zira, Chilov, Chigil, and Sangi-Mugan). In 1931–1932, additional releases were carried out on Chilov, Los, and Gil islands (Ahmadov et al., 2023). Despite the absence of freshwater sources, the rabbits adapted to local conditions and reproduced intensively. Fishermen and crews of small vessels reportedly harvested up to approximately 2,000 individuals annually for food. According to investigations conducted by N.K. Vereshchagin in the 1940s, the species was then recorded only on Gil Island. At present, however, it persists solely on Khara Zira Island.

The fate of the island rabbit populations appears to have been determined by two principal factors: (a) the acute demand for food during 1941–1945, and (b) the establishment of exploration teams on many islands after the 1950s, accompanied by the continuous presence of rotating oil drilling personnel. Disturbance, uncontrolled hunting, and noise from drilling installations led to the decline and disappearance of the rabbits. European rabbits are hunted for their valuable fur and palatable meat. The quality of their fur and meat is comparable to that of domesticated breeds. Their persistence on Gil Island was likely ensured by the establishment of a protected area for the nesting of the great black-headed gull. Saiga antelopes were also introduced there, and game wardens regularly delivered dry fodder by motorboat and filled special reservoirs with drinking water.

The study of skeletal remains of island rabbits from Gil Island revealed morphological differences from their continental relatives, indicating complete feralization. Currently, these rabbits are almost exclusively captured by residents of nearby settlements. Without effective protection measures, they may disappear from Gil Island as well (Vereshchagin, 1942; Vereshchagin, 1947). In Azerbaijan, European rabbits have no special protection status (Ahmadov et al., 2023).

The general biology of Nutria (*M. coypus* M.)

The nutria belongs to the order Rodentia, the family Myocastoridae, and the genus Myocastor (Ahmadov et al., 2023). The species is native to South America, from where it has been introduced to North America, Europe, Asia, and Japan, where it has now established populations. The body length is about 60 cm, with a sparsely furred tail measuring 45 cm. Its weight ranges from 5 to 12 kg, with males slightly larger than females. The hind limbs are longer and larger than the forelimbs, with the 1st–4th toes connected by webbing, measuring 13 cm. The fur consists of coarse guard hairs and dense soft underfur. The body coloration is grayish-brown, lighter on the sides with yellowish tones.

Nutrias inhabit areas with dense vegetation. They build underwater burrows in reeds, cattails, and reed bushes, and dig nests on steep banks. Sometimes, they use burrows of other species, such as beavers and muskrats. The burrow system consists of several tunnels and entrances, with chambers for resting, feeding, and sheltering from adverse weather. Their diet includes roots and various parts of aquatic plants, as well as tree bark. They may also feed on insects, freshwater mussels, and crustaceans.

Nutrias reproduce throughout the year. Reproductive peaks occur in late winter, early summer, and mid-autumn, depending on environmental conditions. Females may suppress estrus or resorb embryos in response to unfavorable ecological conditions. Under optimal conditions, nutrias reach sexual maturity at four months. They breed 2–3 times per year, with non-estrous females entering estrus every 2–4 weeks. Mating lasts 1–4 days, and adult males can mate year-round as they produce sperm continuously. The gestation period is 130–132 days. Females may mate again within 48 hours after giving birth. On average, litters contain 4–5 young, ranging from 1 to 13. Newborns are fully furred, active, and weigh approximately 227 g at birth. They survive shortly after birth by swimming and feeding on plants. Offspring are usually weaned at 7–8 weeks. In the wild, nutrias rarely live more than 3 years, but under controlled conditions, they can live 15–20 years.

When food is abundant, nutrias rest and groom themselves during the day and feed at night. When food is scarce, they search for it during daylight hours. Throughout their lives, nutrias typically remain within a relatively small home range. Their daily movement distance is usually less than 183 meters, although some individuals may travel farther. In winter, nutrias are more active due to increased food requirements. Nutrias have poor vision and rely primarily on hearing to detect danger. They may also use scent to assess the environment. When threatened, they move quickly and take refuge underwater to escape predators. When cornered or captured, nutrias can become aggressive, and their bites and scratches can cause serious injury to humans and domestic animals (LeBlank, 1994; Ahmadov et al., 2023).

Through their feeding and burrowing activities, nutrias cause damage to soil, crops, and even building foundations. They can weaken or destroy natural and artificial dams built for water retention, damage water channels, and cause structures to tilt or collapse. Nutrias can also carry various pathogens and parasites, which may be transmitted to humans, and domestic animals. Therefore, preventive measures are necessary to minimize their impact. In some regions, however, nutrias are protected for economic purposes as fur-bearing animals, and specific permits may be required. Less harmful control methods include live trapping, the construction of fencing and drainage systems, removal of shrubs, trees, and dense vegetation around waterways and wetlands, and regulation of water levels. The use of chemical agents for nutria control is largely unregistered, with only zinc phosphide recognized as a registered toxicant. Shooting can be an effective method for population reduction, but in some states, it is illegal and may only be carried out with proper authorization (LeBlank, 1994). For these measures to be successful, reintroduction and further introduction of nutrias must be halted, and the species should be isolated. Harsh winter conditions help reduce their numbers, and during this period, intensive trapping should continue until the last individual is removed (Carter & Leonard, 2002).

Introduction of the nutria in Azerbaijan (*M. coypus* M.)

This species was introduced into the former USSR from Argentina in 1930–1932. In 1931, the first ten pairs were released into the Gizilaghaj Bay. The rationale for acclimatization included the high commercial value of its fur, the significant nutritional and culinary qualities of its meat, as well as its potential use in fish-breeding reservoirs for the control of marsh vegetation. According to N.K. Vereshchagin (Vereshchagin, 1941), these animals were released in 1932 into the Garasu rivers of the Masalli district; in 1937 into the Eyrichay River in the Zagatala–Shaki valley; in 1940 into Lake Shilyan in the Shirvan steppe; and in 1941 into Aghgol in the Mil plain. In total, 463 individuals were released between 1931 and 1941. Within a short period, nutria considerably expanded beyond the initially designated areas, and its population increased to such an extent that by the 1940s it had already raised the annual fur revenue of Azerbaijan by 35–45%. In 1959, 8,000 pelts were obtained, and in 1969, 58,000 pelts were produced. In subsequent decades, the nutria population exceeded 100,000 individuals.

At present, this species inhabits nearly all lowland districts of southern Azerbaijan, including the Karasu basin systems, lakes and marsh remnants, and the rivers of the Kurdamir, Ujar, Goychay, Saatli, Sabirabad, Barda, Aghdash, Salyan, Masalli, Khachmaz, and other districts. In areas of high population density, nutria farms have been established under cage, semi-free, and free-range management systems (Garayazi, Aghjabadi, Mingachevir, Devechi, Shamkir, and Lankaran farms).

Under the influence of the new environmental conditions, a number of ecological and morphological changes have occurred in local populations of the species. These changes are reflected in body size, fur coloration, timing of sexual maturity, frequency of parturition, and litter size. Thus, the acclimatization of nutria in Azerbaijan can be regarded as entirely successful. Undoubtedly, alongside its economic benefits, it should not be overlooked that the species also serves as a carrier of infectious diseases and leptospirosis pathogens (Vereshchagin, 1941). In Azerbaijan, nutria have no special protection status (Ahmadov et al., 2023).

The general biology of Raccoon (*P. lotor* L.)

Raccoons belong to the order Carnivora, the family Procyonidae, and the genus Procyon (Ahmadov et al., 2023). The genus Procyon includes seven species (Sokolov, 1989). The raccoon is widely distributed in Central and North America. Its acclimatization has been carried out in the West Indies, Germany, and the former USSR. From the release sites, it spread to France and the Netherlands. Since 1936, more than 1,200 individuals have been released in the Russian Far East, Kyrgyzstan, Azerbaijan, the North Caucasus, and Belarus (Sokolov, 1989).

Raccoons have short legs, small, rounded ears, and a body length of 23–50 cm, with a tail measuring 20–40 cm. They have a distinctive black mask bordered with white on the face. The area between the eyes and the cheeks has dull stripes. The tail has 5–7 broad black or dark-brown rings, with a black tip. Their paws are short, but the long toes make their tracks resemble human handprints. The forepaw measures 7 cm, and the hind paw 9 cm. Raccoons can weigh up to 20 kg; females weigh 6.5–9.5 kg, and males 8–15 kg. The fur is long, soft, and grayish-brown, with a dense undercoat (Sarukhanova & Sadiqova, 2019; Ahmadov et al., 2023; Sokolov, 1989).

Raccoons build their dens near marshes, in forests, along rivers among shrubs and reeds, in anthropogenic landscapes, and in tree cavities. They also use above-ground shelters, such as crevices in rocks and burrows of badgers. Although raccoons are excellent climbers, they usually forage on the ground, in marshes, and in shallow water. They are omnivorous, feeding on both plant and animal matter. Their diet includes frogs, crustaceans, fish, rodents (even young muskrats), as well as various berries, acorns, nuts, and fruits. They can also consume household waste. Raccoons use their forepaws to grasp food, and their habit of rinsing prey in water before eating has earned them the nickname "washing bear" (Sarukhanova & Sadigova, 2019; Sokolov, 1989; Aulagnier et al., 2009).

Raccoons are monogamous. Mating occurs in February–March, with estrus lasting about two months. The main birthing period is from April to June (sometimes until October). In the South Caucasus, litters of 3–8 young (usually 4) are born from April to early May. The average litter size is 3–6 offspring. Lactation lasts approximately 50 days. The young open their eyes around the 20th day and begin foraging independently at 4–5 months. Females reach sexual maturity by the end of their first year, while males do so by the end of their second year (Sarukhanova & Sadigova, 2019; Ahmadov et al., 2023; Sokolov, 1989).

Raccoons are crepuscular and nocturnal, hiding in their dens during the day. They typically forage within a 1.5 km radius of their shelter at twilight and night. They are skilled climbers and good swimmers. In mountainous regions, raccoons enter hibernation, though it is not deep and is frequently interrupted. In Canada, hibernation lasts about four months, while in more southern areas it occurs only during snow cover and frost. During mild winters, raccoons do not hibernate (Sarukhanova & Sadigova, 2019; Ahmadov et al., 2023; Sokolov, 1989). The American raccoon is a valuable fur-bearing species and is farmed in specialized facilities in some countries (Sokolov, 1989).

Introduction of the raccoon in Azerbaijan (*P. lotor* L.)

Apart from the European rabbit and the raccoon dog, the raccoon was the third species whose acclimatization in Azerbaijan, regrettably, proved successful. The reason for this regret lies in the fact that raccoons have caused—and continue to cause—considerable damage to the native avifauna and theriofauna. The settlement of this species began in 1941. Between 4 and 9 July of that year, 10 males and 11 females imported from North America (most of the females being in the late stages of pregnancy) were released near the village of Goytepe in the Ismayilli district (Vereshchagin, 1942). Subsequently, the species spread beyond the forests of Ismayilli into other regions. The subsequent history of the raccoon in Azerbaijan was described in detail by Vereshchagin in his well-known monograph on the mammals of the Caucasus (Vereshchagin, 1959): “In 1941, 21 raccoons were released near a village west of Ismayilli. Despite being destroyed by poachers and in village orchards, they rapidly increased both in number and distribution. The entire Eyrichay valley proved suitable for this omnivorous predator. By 1945, the raccoon’s range had reached 250 km^2, and its population numbered 180–200 individuals. By 1949, the inhabited area had expanded to approximately 850–900 km^2, with the population reaching 800–850 individuals. Within the humid and forested lowlands, the rate of raccoon dispersal and range expansion was remarkable, reaching 15–20 km^2 per year under favorable conditions”.

At present, the raccoon is widely distributed in the Zagatala–Ismayilli and Lankaran forest massifs. Local hunters capture it using traps. Despite intensive harvesting, no noticeable decline in population size has been observed. The raccoon is considered one of the harmful species causing damage to game management in Azerbaijan. In Azerbaijan, raccoon have no special protection status (Ahmadov et al., 2023; Sarukhanova & Sadigova, 2019).

Conclusion

Introduction efforts carried out in Azerbaijan show that the adaptation of species to new environments is directly related to their inherent characteristics. Mammalian species successfully introduced into Azerbaijan have demonstrated high adaptive capacity. However, the outcomes of introduction are not always positive. Alongside beneficial species, there are also species that act as pests, carriers of diseases, and other harmful agents. This can result in significant damage to the flora and fauna of the regions where introduction takes place. Such cases have also been observed in introduction processes conducted in Azerbaijan. Therefore, it is essential that, in the continuation of these plans, introduced species are thoroughly studied and kept under strict control. Only under these conditions can introduction processes achieve their intended goals and meet both ecological and economic expectations.

Declaration of 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.

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Nature & Science
April 2026, Vol. 8, Issue 2, pp. 153–157
DOI: https://doi.org/10.36719/2707-1146/65/153-157

Analysis of the Impact of Anthropogenic Activities on the Biochemical Parameters of Water and Hydrobiont Diversity in the Heydar Aliyev Reservoir in Nakhchivan

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Abstract. *In this study, the hydroecological state of the Heydar Aliyev reservoir, located in the Nakhchivan Autonomous Republic, was comprehensively assessed with consideration of ongoing anthropogenic impacts. Water samples were collected and analyzed to determine key biochemical indicators, including nutrient levels, dissolved oxygen, and pH, as well as hydrobiological components such as phytoplankton and zooplankton communities. The study revealed that agricultural activities in the surrounding areas, particularly the use of mineral fertilizers, significantly influenced the reservoir's water quality. Surface runoff from cultivated lands carried excess nutrients into the reservoir, resulting in increased concentrations of nitrogen and phosphorus compounds. These nutrient enrichments triggered alterations in the planktonic structure, including shifts in species composition and abundance, which may have further implications for the overall aquatic ecosystem. Seasonal variations were also observed, indicating periods of higher vulnerability to eutrophication. The findings highlight the strong link between land use practices and the ecological health of freshwater systems. Effective management strategies, including controlled fertilizer application and the implementation of buffer zones, are recommended to mitigate these anthropogenic pressures and preserve the reservoir's ecological balance.*

Keywords: *reservoir, anthropogenic impact, hydrobiology, ecosystem, biochemical*

Introduction

Inland water bodies are of great importance in terms of ecosystem services and are considered to be among the most sensitive natural systems to the impacts of human activity. In addition to providing numerous services such as water supply, fisheries, agriculture, tourism and recreational opportunities, these basins play a key role in protecting biodiversity and ensuring ecological balance. However, in modern times, industrialization, urbanization, intensive agriculture and other anthropogenic activities put serious pressure on inland water bodies.

Anthropogenic pollutants, especially nitrogen and phosphorus compounds, accelerate the eutrophication process by causing trophic changes in the aquatic environment. Eutrophication is characterized by the massive development of phytoplankton and algae in water bodies as a result of an increase in nutrients. This process leads to a decrease in water transparency, limited illumination at depths and a disruption of the oxygen regime of the aquatic ecosystem. As a result, the living conditions of fish and other aquatic organisms in water bodies deteriorate, and in some cases, mass fish deaths are observed.

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Received: 21 December 2025; Accepted: 15 March 2026; Published online: 25 April 2026

Biochemical indicators are the main indicators for assessing the sanitary and ecological state of water. For example, BOD_5 (biochemical oxygen demand) and dissolved oxygen levels reflect the degree of organic pollution. A high BOD_5 level indicates the presence of a large amount of organic matter in water and the need for microorganisms to decompose these substances through oxygen consumption. Nitrate and phosphate ions indicate an increase in anthropogenic nutrients entering water bodies, which is associated with agricultural waste, sewage discharges and industrial emissions.

In addition, monitoring the quality indicators of water bodies is important not only for assessing ecosystem health, but also for protecting public health, sustainable management of water resources and the formation of environmental policy. Modern scientific research shows that an integrated assessment of various physico-linear and biochemical indicators allows for a more accurate and comprehensive determination of the ecological state of water. In this regard, the protection of inland water bodies and the prevention of their pollution are considered one of the main priorities of sustainable environmental management.

Materials and Methods

The object of the study is a reservoir located in a semi-desert climate zone. The area is characterized by high summer temperatures, limited precipitation, and strong evaporation (Guliyeva et al., 2025). Agricultural activity in the reservoir basin area is intensive, which increases the risk of agrochemicals (nitrogen and phosphorus fertilizers, pesticide residues, etc.) entering the aquatic environment. Soil erosion products, suspended particles, and mineral fertilizer residues are transported to the water body through surface runoff resulting from rainfall and irrigation. This can lead to a change in the trophic state and an increase in the concentration of biogenic elements (Paerl & Otten, 2013).

Sampling was carried out during the growing season, which is characterized by a maximum level of biological activity. Samples were selected from three main zones covering the hydrological and ecological characteristics of the reservoir (Ansarova, 2017):
- River inflow area – the main inflow point of foreign substances and nutrients;
- Central aquatorium – a more homogeneous part of the water mass;
- Coastal zone – an area more sensitive to anthropogenic impacts and coastal processes.

In each zone, samples were taken from the surface layer (0–50 cm depth) in sterile glass containers and delivered to the laboratory at a temperature of +4 °C until analysis. Preservation and storage of samples were carried out in accordance with the requirements of international standards (Dodds & Smith, 2016).

Within the framework of the study, the main biochemical and physicochemical indicators of water samples were determined based on international standard methods. The pH indicator was measured electrometrically using a calibrated pH-meter. The concentration of dissolved oxygen (O_2) was determined by the classical Winkler titrimetry method. This method allows to determine the exact amount of oxygen in water and is widely used in assessing the oxygen balance of the aquatic ecosystem.

Biochemical oxygen demand (BOD_5) was calculated based on the 5-day incubation method at a temperature of 20 °C. The difference between the initial and final oxygen indicators reflects the amount of oxygen consumed by microorganisms for the decomposition of organic matter (Wetzel, 2001).

Nitrate (NO_3^-) and ammonium (NH_4^+) ions were determined by spectrophotometric analysis. This method is based on measuring the color intensity formed as a result of the reaction of ions with specific reagents. The amount of phosphate ions (PO_4^{3-}) was determined by the molybdate method;

in this case, the optical density of the complex formed in the reaction with ammonium molybdate was measured.

Results

The results obtained were statistically processed, and average values and standard deviations were calculated. This methodological approach allowed for an objective and reliable assessment of the sanitary and ecological state of the reservoir.

Table 1
Analyses were conducted based on international standard methodologies
(Salmanov & Ansarova, 2018)

Indicator	Method
pH	electrometric
Dissolved O_2	Winkler style
BOD_5	5 days incubation
Nitrate, Ammonium	Spectrophotometric
Phosphate	Molybdate method

Hydrobiological analyses. Plankton samples were collected with a plankton net, and the species composition was determined under a microscope. Biodiversity was calculated using the Shannon index. Plankton samples were collected using a plankton net within the scope of the study. The species composition of the samples was determined under a microscope in laboratory conditions and the presence of each species was recorded. Plankton biodiversity was calculated based on the Shannon index, which allowed assessing the structural diversity and stability of the ecosystem. The main biochemical indicators determined during the study and their evaluation were as follows (Ansarova, 2020):
• pH: was in the range of 7.6–8.3, which indicated that the water was slightly alkaline from neutral.
• Dissolved oxygen (O_2): was recorded in the range of 6.1–8.5 mg/L, which is at a satisfactory level according to the assessment.
• BOD_5 (5-day biochemical oxygen demand): was between 3.2–5.6 mg/L, indicating an average level of pollution (Carpenter et al., 1998).
• Nitrate: The nitrate level of the water was found to be high, which indicates the presence of anthropogenic impacts.
• Phosphate: The phosphate content was high, and this situation was associated with the risk of eutrophication of the water.

These results allow us to determine the state of the ecosystem in terms of both hydrobiological and chemical indicators and assess the degree of anthropogenic impacts (Salmanov & Huseynov, 2013).
Hydrobiological indicators. Green algae and diatoms dominated the species composition of phytoplankton. An increase in cyanobacteria was observed in some areas, which is associated with high nutrient levels. A decrease in zooplankton diversity was recorded. The Shannon index was at an average level, which indicates that the ecosystem is under some degree of stress (Smith et al., 1999).

Disscussion

The results of the study conducted in the Heydar Aliyev reservoir show that the biochemical indicators and hydrobiological diversity of the water were mainly affected by anthropogenic impacts, especially agricultural activities and surface runoff. The increase in nitrate and phosphate concentrations is directly related to the leaching of agricultural fertilizers and soil erosion.

Table 2
Biochemical indicators (Salmanov & Ansarova, 2018)

Parameter	Average value	Assessment
Ph	7.6–8.3	Neutral–weakly alkaline
It's done	6.1–8.5 mg/l	Satisfactory
Bod_5	3.2–5.6 mg/l	Moderate pollution
Nitrate	Elevated	Anthropogenic impact
Phosphate	Elevated	Risk of eutrophication

This has led to a change in the trophic status of the water, especially an increase in phytoplankton biomass (Ansarova, 2016). Green algae and diatoms predominate in the species composition of phytoplankton. This indicates that the amount of nutrients in the aquatic environment is high in certain areas. The growth of cyanobacteria in certain zones indicates potential water bloom tendencies. The decrease in zooplankton diversity is a sign that the trophic chain in the ecosystem is disrupted and some species may be under stress (Ansarova, 2014).

Looking at biochemical indicators, the moderate level of BOD_5 indicates that organic matter has entered the water, but dissolved oxygen has not yet fallen to a critical level. This means that the oxygen regime in the reservoir is still stable, but in the future, if the amount of nutrients increases and the temperature rises, the problem of oxygen deficiency may arise (Ansarova, 2016). The research results show that the anthropogenic impact is mainly stronger in the river inlet area and the coastal zone. This indicates that some parts of the reservoir are more ecologically sensitive. If this situation continues, the change in plankton structure will become more widespread and the accumulation of high nutrients will negatively affect ecosystem functions (Salmanov & Huseynov, 2013). These results also indicate that there are potential ecological risks in irrigation and domestic water use in the surrounding areas. Therefore, continuous water monitoring, keeping nutrient levels under control and managing runoff from agricultural areas is important (Ansarova, 2014).

Conclusion

This has led to a change in the trophic status of the water, especially an increase in phytoplankton biomass. Green algae and diatoms predominate in the species composition of phytoplankton. This indicates that the amount of nutrients in the aquatic environment is high in certain areas. The growth of cyanobacteria in certain zones indicates potential water bloom tendencies. The decrease in zooplankton diversity is a sign that the trophic chain in the ecosystem is disrupted and some species may be under stress.

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Signed: 19.04.2026
Online publication: 25.04.2026
Paper printing: 10.05.2026
Format: 60/84, 1/8
Stock issuance: 20 p.s..
Order: 161

It has been published in the printing house
"ZANGAZURDA"
Address: Baku city, Yasamal dist.,
A.M.Sharifzade 19
Phone: +994 12 510 63 99
e-mail: zengezurda1868@mail.ru