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MULTIFACTORIAL ASSESSMENT OF AGROBIOLOGICAL RESPONSES OF *CICER ARIETINUM* L. TO HIGH-TEMPERATURE STRESS IN AGROCENOSES OF THE AZERBAIJAN REPUBLIC

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ABSTRACT

This study aimed to agrobiologically evaluate the developmental stability of *Cicer arietinum* L. under high-temperature stress in agrocenoses of Azerbaijan, using seed germination and fluctuating leaf asymmetry as key indicators. We also studied key mitochondrial enzymes over the last 3 years. Initially, we assessed the heat tolerance of three varieties based on germination at 25 ± 2°C. The variety 'Ulunana' showed the highest germination (68%) and was selected for further analysis. Plants were exposed to controlled temperature regimes for three days, simulating both short-term (35 ± 2°C for 5 h/day) and long-term (35 ± 2°C day/25 ± 2°C night) heat stress. FA was measured as an indicator of developmental stability, along with the dynamics of photosynthetic pigments. The results showed a clear increase in bilateral leaf asymmetry, variance, and FA values under stress. Under STS, bilateral asymmetry increased by 1.43 times, and under LTS, by 1.76 times compared to the control group. The FA index increased by 1.95 times after short-term heat exposure and by approximately 3 times after long-term heat exposure. Analysis of photosynthetic pigments revealed compensatory responses within 14–17 days, followed by a significant decrease in chlorophyll and carotenoid content by day 21, indicating depletion of photoprotective mechanisms. Day 14 was identified as a critical ontogenetic threshold, beyond which adaptive capacity is gradually exhausted. These results indicate that high temperature stress significantly disrupts the developmental homeostasis of chickpea plants and highlight the utility of FA as a sensitive integrative biomarker for identifying heat-tolerant genotypes. We analyzed comparative additive main effects and multiplicative interactions in 2023, 2024, and 2025.

Keywords: Agro productivity, Heat stress, Agrobiological parameters, Developmental stability, Photosynthetic pigments, Thermotolerance, Bioindication.

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1. INTRODUCTION

These plants are valuable agricultural crops and important protein producers in many countries, including our Republic of Azerbaijan. One of the main factors determining their yield is effective protection from pests and diseases. The natural and climatic conditions in many regions of Azerbaijan favor the normal development and overwintering of the main pests and pathogens of these plants. Plant viruses circulate here, affecting economically important crops: vegetables, cereals, legumes, and ornamentals. One common and harmful legume disease is legume necrosis, caused by viruses. The rapid production of reactive oxygen species (ROS), associated with the oxidative burst, is one of the earliest plant responses to pathogen infection. ROS are toxic to the pathogen and can also serve as second messengers that activate genes expressing protective proteins. In response to pathogen infection, defense mechanisms are activated, including increased barrier properties (lignification), gene expression, and the synthesis of a number of proteins, including enzymes, among which antioxidant enzymes play a special role (Asati et al., 2022; Akbarova & Mammadova, 2024; Ali et al., 2025; Abbas et al., 2026). Various plant species show increased activation of antioxidant enzymes in response to infection (fungal, bacterial, viral, etc.). Plant cells possess a powerful defense system against oxidative stress. This system includes enzymes such as superoxide dismutase (SOD), ascorbate peroxidase (APO), catalase (CAT), and glutathione reductase, as well as non-enzymatic elements such as carotenoids, α-tocopherol, ascorbate, and others. Several experimental observations indicate the significant role of these enzymes in plant resistance to pathogens. Leguminous crops such as beans, peas, chickpeas, and lentils play a key role in the food security programs of many countries. Their high protein, fiber, vitamins, and essential amino acids make them indispensable sources of nutrition, while their use as feed for farm animals further underscores their economic

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importance (Asadli et al., 2025; Allahverdi et al., 2026; Ahmad et al., 2026). They also possess significant agrotechnical value: through symbiosis with nitrogen-fixing bacteria, they enrich soil with biologically available nitrogen, improve soil fertility, and serve as important precursors in crop rotation systems, helping reduce fertilizer costs and suppress weeds and pathogens. Promoting legume production thus directly supports food security, maintains agricultural sustainability, and protects environmental quality. It is valued for its rich protein content, essential amino acids, dietary fiber, vitamins, and minerals, and plays a critical role in sustainable agriculture through atmospheric nitrogen fixation and soil fertility improvement. Despite its agronomic importance, productivity is highly sensitive to abiotic stresses, particularly high temperatures - a threat that is being amplified by ongoing anthropogenic climate change. The Intergovernmental Panel on Climate Change projects a global temperature increase of 1.5°C between 2030 and 2052, which will substantially increase the incidence of thermal stress events across agricultural regions. Heat stress, particularly during critical reproductive stages, can cause substantial yield losses in chickpea, with temperatures exceeding 35°C reducing yields by up to 39%. Previous studies have documented that high temperature induces significant changes in morphometric traits of *C. arietinum* L., including alterations in leaf characteristics and root length, while disturbances in shoot and root growth parameters under elevated temperatures have also been reported (Baran et al., 2022; Devi et al., 2022; Danakumara et al., 2024; Fazeli-Nasab et al., 2025; Bahram et al., 2025). Agrobiological characteristics of root and shoot systems have been proposed as additional indicators for efficiently selecting stress-tolerant genotypes. Developing heat-tolerant varieties is therefore a critical priority; identifying potential heat-tolerant landraces is a valuable strategy for heat-stress tolerance breeding programs. During their development, plants interact actively with a variety of environmental factors, both abiotic and biotic. To adapt to adverse conditions, they deploy a range of physiological and biochemical mechanisms, which are ultimately reflected in anatomical and morphological changes (Gahramanova et al., 2026; Mammadova et al., 2026a). Plant resistance to abiotic stressors is determined by the capacity to maintain functional activity under adverse conditions - an ability that is genetically determined but typically becomes phenotypically expressed only under stress-inducing conditions. Consequently, assessing plant resistance requires subjecting experimental specimens to specific stress conditions to evaluate adaptive responses (Ibrahimova et al., 2024; Hasanova et al., 2026). For assessing plant tolerance to extreme environmental conditions, the developmental stability evaluation method based on leaf FA is widely used. Fluctuating asymmetry, defined as random non-directional deviations from perfect bilateral symmetry in morphological traits, serves as a sensitive indicator of environmental stress and genetic perturbation during development, reflecting the organism's inability to maintain precise developmental pathways under adverse conditions. Studies employing FA as a bioindication tool have demonstrated its utility across a range of taxa and stress scenarios, including urban pollution assessment, forest ecosystem monitoring, and evaluation of plant species under contrasting environments. The photosynthetic pigment system - comprising chlorophylls a and b, and carotenoids - constitutes the primary interface between the plant and its light environment (Huseynova, 2022; Huseynova, 2023; Ismayilova et al., 2025a; Ismayilova et al., 2025b). Chlorophyll a, the principal reaction center pigment, is particularly sensitive to heat stress, while chlorophyll b functions in light-harvesting complexes. Carotenoids serve dual roles as accessory pigments and photoprotective agents, quenching excess excitation energy and scavenging reactive oxygen species. The chlorophyll a/b ratio serves as a sensitive indicator of photosystem stoichiometry and PSII integrity, with reductions reflecting preferential degradation of reaction center components. High temperatures significantly impair photosynthesis by damaging chloroplasts, altering stomatal conductance, and reducing chlorophyll content, thereby affecting overall plant productivity. The concentration of chlorophyll and other photosynthetic pigments therefore serves as a key indicator of the functional integrity of the photosynthetic apparatus and reflects the plant's overall physiological status (Jha et al., 2023; Jabeen et al., 2024; Ismayil et al., 2025). The indicative and remedial properties of leguminous plants under stress have been documented in earlier work with *Vicia faba* L., providing a methodological foundation for the present investigation using *C. arietinum* L. Based on the above, the aim of the present study was to assess the impact of high temperatures on the developmental stability using seed germination rates, leaf fluctuating asymmetry, and photosynthetic pigment dynamics as complementary indicators across ontogenetic stages (Mamedova, 2009; Katkani et al., 2022; Kumar et al., 2023; Ibrahimova, 2025).

2. MATERIALS AND METHODS

2.1. Experimental Period

Chickpea (*Cicer arietinum* L.), a species belonging to the genus *Cicer* L. of the family *Fabaceae* (*Leguminosae*). Three local varieties, "Sultan", "Narmin", and "Ulunana," were obtained from the Scientific Research Institute of Crop Husbandry. Before the experiment, seeds were cold-stratified in complete darkness for 7 days at 5°C and 30% relative humidity to break dormancy and synchronize germination. After stratification, seeds were surface-sterilized with 3% hydrogen peroxide (H_2O_2), thoroughly rinsed with distilled water, and soaked in distilled water for 12 hours.

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2.2. Germination Period

The germination period was carried out using distilled water in sterile glass Petri dishes, maintained in darkness at 25 ± 2°C and 45% relative humidity. A total of 50 seeds per variety were assessed; germination was recorded after 3 days and expressed as a percentage of seeds producing radicles. A total of 120 seeds of the selected "Ulunana" variety were sown in a 2:1 mixture of black soil and bio-mix fertilizer and grown under controlled conditions at 25 ± 2°C (day) and 16 ± 2°C (night). On days 7 and 14, plants were transferred to growth chambers for temperature stress treatments (Palmer & Strobeck, 1986; Mammadova et al., 2017; Mammadova & Mammadova, 2019; Mammadova & Mammadova, 2020). Three experimental groups were established: Control group (CT): Plants maintained under optimal temperature conditions throughout the entire experimental period (daytime: 25 ± 2°C; nighttime: 16 ± 2°C). Short-term stress group (STS): Plants exposed to 35 ± 2°C for 5 hours per day over three consecutive days, followed by return to optimal conditions for the remaining hours. Long-term stress group (LTS): Plants maintained under continuous high-temperature conditions for three days (daytime: 35 ± 2°C; nighttime: 25 ± 2°C). Environmental parameters: soil pH, temperature, moisture, and air humidity were continuously monitored throughout the experiment using appropriate instruments (Mammadova et al., 2024a, 2024b, 2024c).

2.3. Fluctuating Asymmetry Assessment

The degree of plant resistance to high-temperature stress was evaluated using the fluctuating asymmetry (FA) method. The primary measured trait was the maximum distance from the central (main) vein to the right and left margins of the leaf blade. Leaf measurements were analyzed using software developed by the authors, which utilized established formulas to calculate key developmental stability indicators: bilateral asymmetry (Δd), dispersion, and the fluctuating asymmetry coefficient. FA was measured at five ontogenetic time points (days 7, 10, 14, 17, and 21 post-sowing) across all three experimental groups (Mammadova et al., 2025a; Mirzezadeh et al., 2025). On the 7th day the pigments are very weak. Fresh leaf samples (0.1 g) were collected from fully expanded leaves at days 10, 14, 17, and 21. Samples were homogenized in 80% aqueous acetone and filtered through filter paper (Palmer & Strobeck, 1986). We measured extract absorbance at 663 nm, 646 nm, and 470 nm using a UV-Vis spectrophotometer. Concentrations of Chl_a, Chl_b, and total carotenoids were calculated. All pigment analyses were performed in triplicate. The chlorophyll a/b ratio was calculated as an indicator of photosystem stoichiometry and reaction center integrity. Morphometric analysis encompassed measurement of root length, stem height, and leaf blade dimensions (length and width) at each experimental time point. We measured parameters with digital calipers to the nearest 1 mm. Coefficient of variation (CV) was calculated for each parameter within each group as (SD/mean) × 100 to quantify intra-group variability dynamics. We used a multivariate dimension-reduction technique for analysis; visualization style: PCA Biplot (displays both sample groupings and variable vectors simultaneously). Principal Component 1 (PCA1, explaining 24.22% variance) and Principal Component 2 (PCA2, explaining 42.21% variance). Correlation between plant parameters (e.g., shoot/root nitrogen, phosphorus, potassium) and soil environmental variables (e.g., soil organic matter, enzymes like NAGase, URase).

2.4. Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics version 26.0. Data were tested for normal distribution and homogeneity of variances. To account for the repeated-measures design across multiple time points (days 7, 10, 14, 17, and 21), a two-way repeated-measures analysis of variance ($\alpha = 0.05$) was used to evaluate the main effects of treatment, time, and their interaction (treatment × time). Pearson's correlation analysis was used to examine the relationship between PA indices and photosynthetic pigment concentrations. Results are presented as mean ± standard deviation (Mirismayil, 2025; Mammadova et al., 2025b; Makki et al., 2025).

3. RESULTS & DISCUSSION

3.1. Genotypic Variation and Germination Capacity in Chickpea Cultivars

The initial cultivar screening revealed significant genotypic variation in germination capacity among the three tested chickpea cultivars under optimal temperature conditions (25–27°C). The 'Ulunana' cultivar achieved the highest germination capacity (88 ± 3.2), followed by 'Narmin' (76 ± 4.1) and 'Sultan' (68 ± 5.0), establishing a clear genotypic hierarchy: Ulunana (88%) > Narmin (76%) > Sultan (68%). These differences in germination performance likely reflect cultivar-specific variation in seed vigor, reserve mobilization efficiency, and early embryonic thermotolerance - traits that may partially cosegregate with broader stress adaptation capacity. Selecting 'Ulunana' for the experimental phase aligns with established practices in plant stress physiology research, where cultivars with the highest baseline performance are used to ensure reliable detection of stress-induced changes. The superiority of 'Ulunana' may relate to its seed biochemical composition, embryo size, or the efficiency of starch-to-sugar conversion during germination, though these mechanistic aspects warrant further biochemical investigation (Samadov et al., 2026; Gahramanova et al., 2026).

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These plots (Fig. 1 A-E) visualize the relationship between genotype performance and environmental stability. Genotypes located in Quadrant IV are generally the most desirable for yield, as they have high mean performance and low variability (high stability). The spread of the red diamonds shows how much the testing years differed. In all plots, 2023 appears as a distinct outlier compared to 2024 and 2025. In plot C, most genotypes cluster tightly around 165 days for flowering, suggesting low genetic variation for this trait compared with the environmental influence of different years (Nazim & Oqtay, 2024).

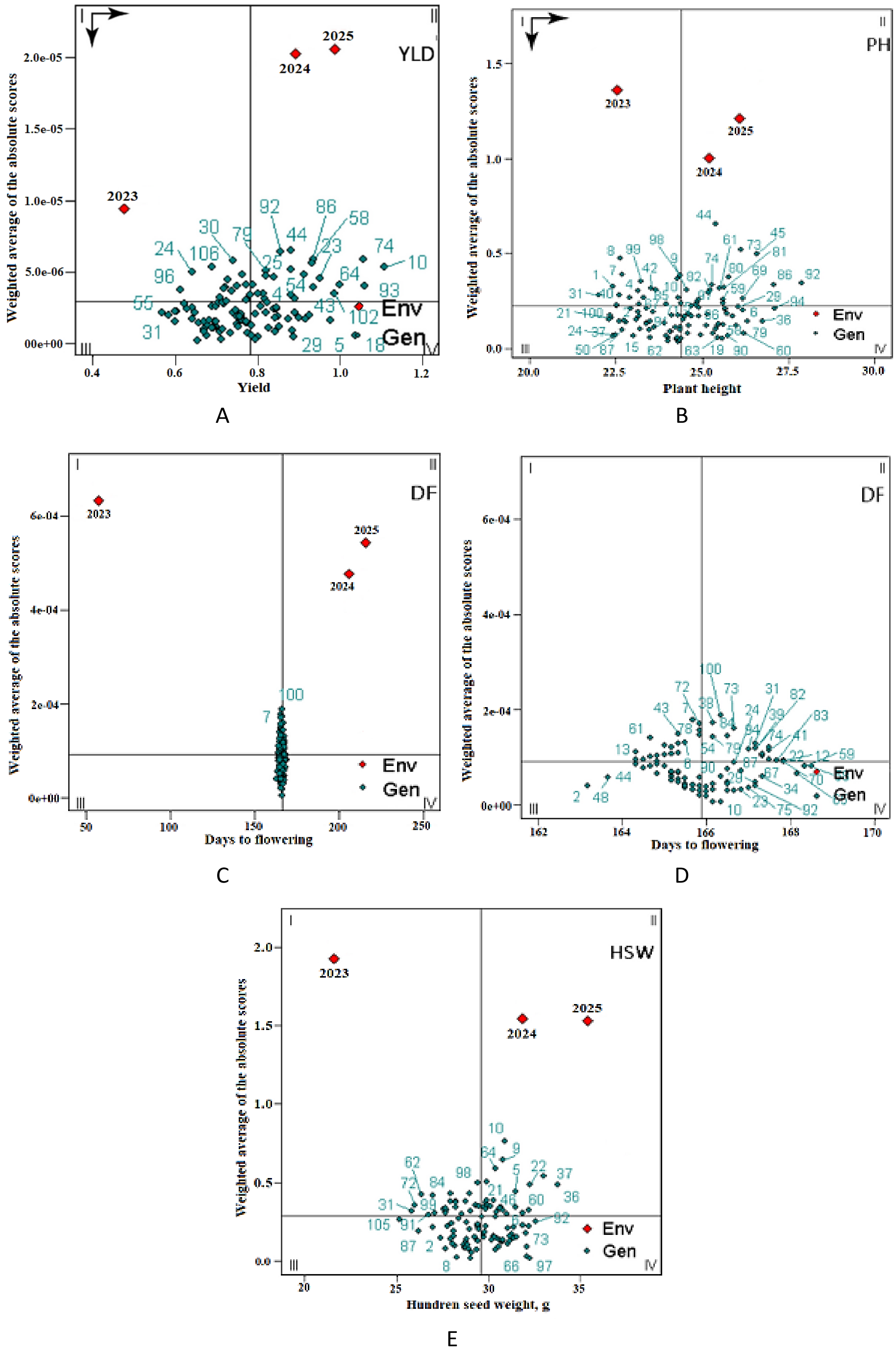

Fig. 1: Additive Main Effects and Multiplicative Interaction in 2023, 2024, and 2025. PH – Plant height; YLD – Yield; DF – Days to flowering; WAASB (Weighted Average of Absolute Scores), which measures stability. Gen: Represents different genotypes; Env: Represents specific environments/years.

3.2. Antioxidant Enzymes and Soil Fertilizer Interactions

The combined action of antioxidant enzymes: superoxide dismutase, catalase, and glutathione peroxidase. SOD converts superoxide radical anions into hydrogen peroxide. Physiological levels of hydrogen peroxide are maintained by catalase (Fig. 2). The effect of phosphorus and potassium fertilizers on the content of mineral nitrogen in the soil

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when planting legumes. The variables showed interactions (Fig. 3A and 3B).

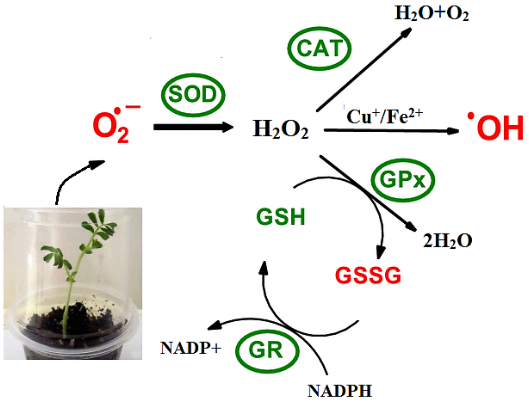

Fig. 2: Enzymatic activity in *Cicer arietinum* L. mitochondria. GPx - glutathione peroxidase; GSH - reduced glutathione; GSSG - glutathione disulfide; GR - glutathione reductase; NADPH - nicotinamide adenine dinucleotide phosphate; NADP - an oxidized form ($NADP^+$) and a reduced form (NADPH) to transfer energy; Cu and Fe - redox metals.

3.3. Leaf Developmental Stability and Asymmetry under Heat Stress

Analysis of the distribution of leaf bilateral asymmetry (Δd) under control and stress conditions revealed clear differences in developmental stability across temperature regimes (Table 1). Under control conditions (25 ± 2°C day/16 ± 2°C night), more than 85% of the leaves exhibited low asymmetry (Δd≤0.5 mm), indicating high developmental stability. The distribution was strongly left-skewed, consistent with a normally functioning developmental homeostasis system (Mammadova & Mammadova, 2019). Plants subjected to short-term heat stress (35 ± 2°C for 5 hours over 3 days) showed a significant redistribution of asymmetry values: the proportion of leaves in the low-asymmetry range (Δd≤0.5) decreased to 60%, while the frequency distribution broadened with a secondary peak near Δd = 1.0–1.1 mm. This reflects the onset of developmental disturbances induced by thermal perturbation.

Under continuous heat stress (35 ± 2°C day/25 ± 2°C night for three days), asymmetry increased markedly. Less than 40% of leaves remained in the low-asymmetry range, and the distribution became irregular and broad, with measurable values exceeding Δd = 2.0 mm. This pattern indicates a clear decrease in developmental homeostasis and an increase in phenotypic variability, confirming a strong destabilizing effect of prolonged high temperature exposure - consistent with findings reported for other plant species under abiotic stress (Nasirova, 2023a; Nasirova, 2023b).

Table 1: Percentage distribution of *C. arietinum* leaves by bilateral asymmetry range (Δd) under contrasting temperature regimes

Bilateral Asymmetry Δd (mm)	Control 25±2/16±2°C (%)	Short-term stress 35 ± 2°C, 5 h/day (%)	Long-term stress 35 ± 2/25 ± 2°C (%)
0.0 – 0.5	85	60	38
0.6 – 1.0	10	25	30
1.1 – 1.5	10	10	20
1.6 – 2.0	1	4	8
> 2.0	1	1	4

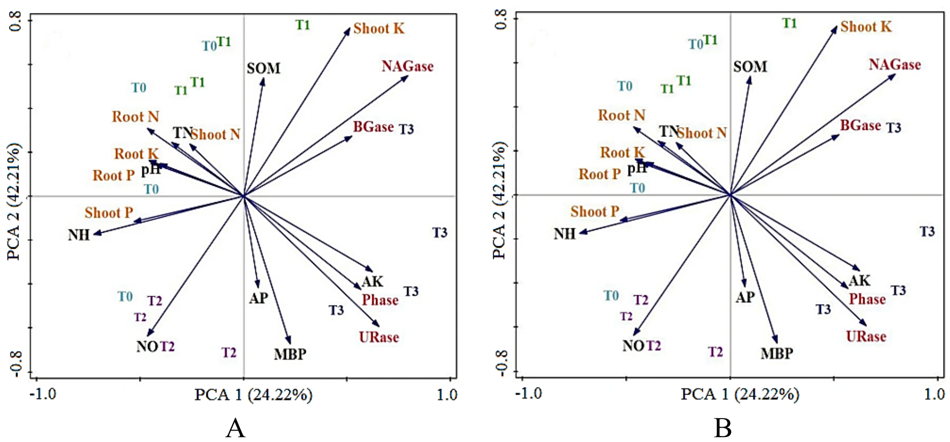

Fig. 3: Principal component analysis (PCA) showed the general relationship between plant phosphate uptake in shoots and roots, soil enzymes, and soil properties in two different legumes: (A) fertilized chickpea and (B) unfertilized chickpea. The properties of NAGase (N-acetylglucosaminidase), BGase (β-glucosidase), Phase (phosphatase), URase (urease), TN (total nitrogen), NH_4^+ (ammonium), NO_3 (nitrate), SOM (soil organic matter), and AP, AK (available phosphorus and potassium).

Fluctuating asymmetry index (FA) values are monitored over a 21-day period of development (ontogenesis). FA measures small random deviations from perfect bilateral symmetry, which typically indicate environmental or genetic stress during development. The experiment compares three different groups under different temperature conditions (Table 2). Beginning at day 14, FA indices in both stress groups increased sharply and significantly, while remaining stable or marginally decreasing in the control group. By day 21, the FA index in LTS plants (0.134 ± 0.026) was approximately 3.8-fold higher than in control plants (0.035 ± 0.006), and approximately 1.6-fold higher than in STS plants (0.083 ± 0.018). The variance (dispersia) of FA values also increased in stress groups over time, reflecting growing inter-individual heterogeneity in the precision of developmental processes, a pattern consistent with

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increased stochastic developmental error under thermal stress. Critically, the increase in FA after day 14 was precisely synchronized with intensified morphometric growth suppression and the subsequent decline in photosynthetic pigments. This temporal concordance strongly supports the interpretation that FA elevations reflect genuine disruption of developmental homeostasis rather than stochastic sampling variation. Under control conditions, the decreasing CV for morphometric traits combined with stable or decreasing FA suggests that developmental canalization was maintained throughout i.e., genetic developmental programs were being executed with high precision. Under LTS conditions, in contrast, the declining morphometric CV combined with sharply increasing FA creates an apparent paradox that is resolved by distinguishing between two sources of population-level uniformity: in the control, uniformity reflects similar high-performance growth trajectories; in the LTS group, uniformity reflects similar growth limitation, all individuals being constrained to comparably low growth rates while the precision of bilateral development simultaneously deteriorates. These findings extend previous work demonstrating the utility of FA as a stress biomarker in plants and specifically validate its application in chickpea under thermal stress conditions. The identification of day 14 as the critical inflection point for FA elevation suggests that FA monitoring beginning around the second week of ontogenesis could provide early warning of impending physiological dysfunction in field conditions, prior to the manifestation of severe yield penalties. Temporal analysis further revealed that at day 7, FA values were comparably low across all groups, indicating that early-stage developmental programs were adequately buffered against initial thermal perturbation. Beginning at day 14, FA indices in stress groups increased sharply and significantly, while remaining stable in controls. This temporal inflection at day 14 is consistent across all measured indicators and is discussed below in an integrative framework.

Table 2: Fluctuating asymmetry (FA) index values across ontogenetic stages under different temperature regimes

Day	Control (FA index)	Short-term Stress (FA index)	Long-term Stress (FA index)
7	0.042 ± 0.008	0.045 ± 0.009	0.048 ± 0.010
10	0.040 ± 0.007	0.052 ± 0.011	0.061 ± 0.013
14	0.038 ± 0.007	0.071 ± 0.015	0.089 ± 0.018
17	0.036 ± 0.006	0.078 ± 0.017	0.112 ± 0.022
21	0.035 ± 0.006	0.083 ± 0.018	0.134 ± 0.026

Table 3: Stem height (cm) of *C. arietinum* 'Ulunana' across ontogenetic stages under contrasting temperature regimes

Day	CT	CV%	STS	CV%	LTS	CV%
7	5.28 ± 0.57	10.79	5.23 ± 0.56	10.79	5.20 ± 0.55	10.59
10	9.14 ± 0.74	8.10	8.45 ± 0.64	7.57	7.83 ± 0.62	7.92
14	13.52 ± 0.72	5.34	11.89 ± 0.65	5.49	10.44 ± 0.68	6.52
17	16.73 ± 0.68	4.06	14.21 ± 0.85	5.98	11.98 ± 0.67	5.59
21	19.28 ± 0.62	3.24	16.56 ± 1.25	7.54	13.56 ± 0.74	5.54

3.4. Morphometric Growth Dynamics

Morphometric analyses showed that heat stress caused reductions in all measured growth parameters: stem height, root length, and leaf dimensions, with the magnitude of suppression increasing with stress duration (mean ± SD, n = 5) (Table 3). At day 7, all groups exhibited nearly identical stem heights (approximately 5.2–5.3 cm), confirming that initial stress had not yet produced measurable morphological consequences. By day 21, the control plants (CT) reached 19.28 cm, while short-term stress (STS) plants achieved 16.56 cm (14.1% reduction) and long-term stress (LTS) plants only 13.56 cm (29.7% reduction). The temporal trajectory of the CV provided additional mechanistic insight. In the control group, CV decreased monotonically from 10.79% (day 7) to 3.24% (day 21), reflecting coordinated, genetically programmed growth, a hallmark of normal development. In the LTS group, CV also decreased (from 10.59% to 5.44%), but for a fundamentally different reason: thermal stress imposed uniform growth suppression across all individuals, eliminating phenotypic diversity not through coordinated development but through convergent developmental limitation. As expressed in the core interpretive principle: under control conditions, CV decrease reflects coordinated development; under stress conditions, it reflects uniform growth inhibition. The STS group showed a non-monotonic CV pattern initially decreasing (to 5.49% at day 14) then rebounding to 7.54% by day 21, indicating the emergence of inter-individual variation in stress tolerance as some plants adapted more effectively than others to the intermittent thermal regime. This divergence in adaptive capacity has direct implications for genotypic selection, as it suggests that intermittent heat exposure reveals latent inter-genotypic variation not visible under continuous stress.

3.5. Photosynthetic Pigment Dynamics and Photoprotective Exhaustion under Thermal Stress

Spectrophotometric analysis of photosynthetic pigments revealed a stage-dependent response pattern that differed qualitatively between temperature treatments (Table 3). In the control group, all pigment concentrations Chl a, Chl b, total chlorophyll (Chl a+ Chl b), and carotenoids showed continuous progressive increases from day 10 through day 21, consistent with normal chloroplast biogenesis and leaf maturation. In both stress groups, compensatory dynamics were observed during days 10–17: pigment concentrations continued to increase, and the short-term stress group even reached its highest total chlorophyll value (234.2 mg/100 g FW) at day 17, marginally exceeding the control (233.5 mg/100 g FW). Elevated carotenoid concentrations at day 10 in stress groups (STS: 98.2; LTS: 110.0 mg/100 g FW) relative to controls (84.3 mg/100 g FW) reflect early upregulation of photoprotective defense mechanisms. However, by day 21, the dynamics reversed. In both stress groups, Chl a, total chlorophyll, and carotenoids fell significantly below control values. Chl a in LTS plants declined to 125.7 mg/100 g FW (versus 183.3

in controls), while carotenoids fell to 105.5 mg/100 g FW (versus 147.0 in controls). Carotenoid depletion at this stage indicates exhaustion of the photoprotective defense system, leaving the photosynthetic apparatus without adequate antioxidant protection. The chlorophyll a/b ratio provided sensitive mechanistic insight into photosystem integrity. Under control and STS conditions, the ratio remained relatively stable (2.21–2.31), indicating maintained photosystem stoichiometry. Under long-term stress, however, the ratio progressively declined from 2.23 (day 10) to 1.84 (day 21), reflecting preferential degradation of Chl a concentrated in photosystem reaction centers and indicating functional damage to the photosynthetic apparatus. This pattern confirms that morphometric, FA, and pigment analyses converge on a single interpretive framework: prolonged thermal stress progressively exhausts the adaptive capacity of *C. arietinum.*

The convergent evidence from all three measurement systems morphometric parameters, FA indices, and photosynthetic pigments consistently identifies day 14 of ontogenesis as a critical threshold beyond which the adaptive capacity of chickpea plants is progressively overwhelmed under sustained heat stress. Prior to day 14 (days 7–14), all indicators suggest retention of meaningful adaptive buffering: growth continued (at reduced rates under stress), FA values remained relatively low, and photosynthetic pigments showed compensatory trends. From day 14 onward under long-term stress, the trajectory shifted qualitatively: morphometric growth inhibition accelerated, FA indices rose sharply, and photosynthetic pigments - particularly carotenoids began their terminal decline. This temporal convergence demonstrates that FA elevation and pigment decline are not independent phenomena but reflect a common underlying deterioration of systemic homeostasis. FA acts as an integral express indicator of both external (morphological) and internal (physiological) deviations in plant development, making it suitable for early diagnosis of heat stress and screening of heat-resistant genotypes. From a practical standpoint, identifying day 14 as a critical sensitivity window implies that agricultural interventions, such as supplementary irrigation, shading, or application of stress protectants, must be deployed before this threshold to be maximally effective. The FA method, combined with photosynthetic pigment monitoring, thus provides a powerful, non-invasive toolkit for early warning of impending physiological dysfunction in chickpea under heat stress conditions (Mammadova et al., 2026a; 2026b; 2026c; Verdiyeva et al., 2026).

4. CONCLUSION

High-temperature stress caused a progressive, dose-dependent decline in all morphometric parameters (stem height, root length, and leaf size) in chickpea, with growth retardation significantly intensifying after day 14 of ontogenesis. Population-level coefficient of variation dynamics revealed that stress-induced population homogenization reflected growth restriction rather than developmental coordination, a distinction that is important for interpreting data on variability under stress. Fluctuating asymmetry indices showed a critical inflection point after day 14, sharply increasing in stressed plants, especially under prolonged, continuous stress, while remaining stable in control plants. The parallel trajectories of increasing PA levels and decreasing photosynthetic pigmentation, along with their significant negative correlation, show that PA serves as an integrative biomarker encompassing both external morphological instability and internal physiological deterioration, making it a uniquely informative single-parameter indicator of systemic stress-induced dysfunction. Analysis of photosynthetic pigmentation revealed a biphasic response under short-term stress (early compensation followed by decompensation) and a more profound, early degradation under prolonged stress. A decrease in the chlorophyll a/b ratio from 2.23 to 1.84 under prolonged stress indicates selective degradation of the photosystem reaction centers, while carotenoid depletion by day 21 signals exhaustion of the photoprotective mechanism. Taken together, these results establish day 14 of chickpea ontogeny as a critical vulnerability threshold for prolonged heat stress, beyond which the plant's adaptive buffering capacity is gradually exhausted. This threshold has direct practical implications for developing agronomic management strategies, including irrigation scheduling, shading, and the timing of protective measures, in chickpea cultivation systems subject to heat stress. Confirming FA's role as an integrative, early-warning biomarker opens promising opportunities to develop rapid, non-destructive field screening methods for identifying heat-tolerant genotypes in chickpea improvement programs.

Declarations

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Data Availability: All the data is available in the article.

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REFERENCES

Abbas, S. M., Ijaz, R., Hussain, T., Haider, M. W., Nafees, M., Stanciu, A. S., Shokeralla, A. A., İbrahimova, U., & Rzayeva, A. (2026). Plant spacing modulates growth, yield and nutrient dynamics of sponge gourd under semi-arid conditions. Scientific Reports, 16(1), 18976. https://doi.org/10.1038/s41598-026-50235-5

Ali, S., Muhammad, N., Khan, R.A., Ali, L., Khan, S., Ahmad, S., Amin, S., Khan, H., Fazal, H., & Ahmad, N. (2025). Comparative antioxidant potential in various anatomical structures of Parthenium hysterophorus before and after flowering. Agrobiological Records, 21, 1-9. https://doi.org/10.47278/journal.abr/2025.028

Asati, R., Tripathi, M. K., Tiwari, S., Yadav, R. K., & Tripathi, N. (2022). Molecular breeding and drought tolerance in chickpea. Life (Basel), 12(11), 1846. https://doi.org/10.3390/life12111846

Ahmad, P. S., Latifaga, A. R., Mirismayil, M. A., Ikhtiyar, A. N., Nazim, R. M., Telman, V. M., Aghayeva, T. S., & Shirinova, G. F. (2026). Eco-biological features of mountain gray-brown development in the Karabakh steppe (Republic of Azerbaijan). International Journal of Agriculture and Biosciences, 15(4), 1691-1699. https://doi.org/10.47278/journal.ijab/2026.063

Akbarova, C., & Mammadova, A. (2024). Chorological analysis and phenological observations of some species of the family Crassulaceae J.ST.-HIL. in the Lesser Caucasus of Azerbaijan. Advances in Biology and Earth Sciences, 9(2), 301-309. https://doi.org/10.62476/abes9301

Allahverdi, T. H., Musa, A. J., Maharram, S. H., Gudrat, V. I., Israphil, G. M., Madnee, M. & Farhad, G. A. (2026). Modeling humus stocks and introducing a saturation coefficient to assess soil organic carbon capacity in forest soils of the Sheki-Zagatala Region, Azerbaijan. International Journal of Agriculture and Biosciences, 15(5), 1969-1977. https://doi.org/10.47278/journal.ijab/2026.116

Asadli, A., Mammadova, R., & Mammadova, A. (2025). Assessing heat stress tolerance in Cicer arietinum L. using leaf fluctuating asymmetry in the context of climate change. Baku State University Journal of Life Sciences & Biology, 2(4), 38–41. https://doi.org/10.30546/300045.2025.2.4.3032

Bahram, F. V., Allahverdi, T. H., Eyvaz, M. I., Yusif, E. H., Elshad, T. J. & Farhad, G. A. (2025). Bioecological characteristics of modern soil cover in subtropic regions of Azerbaijan. International Journal of Advances Applied Sciences, 14(4), 1200-1207. https://doi.org/10.11591/ijaas.v14.i4.pp1200-1207

Baran, A., Baran, M., Keskin, C., Hatipoğlu, A., Yavuz, Ö., Kandemir, S., Adican, M. T., Khalilov, R., Mammadova, A., Ahmadian, E., Rosić, G., Selakovic, D., & Eftekhari, A. (2022). Investigation of antimicrobial and cytotoxic properties and specification of silver nanoparticles (AgNPs) derived from Cicer arietinum L. green leaf extract. Frontier Bioengineering Biotechnology, 10, 855136. https://doi.org/10.3389/fbioe.2022.855136

Danakumara, T. N., Kumar, S., Patil, B. S., Kumar, A., Bharadwaj, C., Jain, M., Nimmy, M. S., & Joshi, P. (2024). Unraveling the genetics of heat tolerance in chickpea landraces (Cicer arietinum L.) using genome-wide association studies. Frontiers in Plant Science, 15, 1372283. https://doi.org/10.3389/fpls.2024.1372283

Devi, P., Jha, U. C., Prakash, V., Kumar, S., Parida, S. K., Paul, P. J., Prasad, P. V., Sharma, K. D., Siddique, K. H., & Nayyar, H. (2022). Response of physiological, reproductive function and yield traits in cultivated chickpea (Cicer arietinum L.) under heat stress. Frontiers in Plant Science, 13, 880519. https://doi.org/10.3389/fpls.2022.880519

Fazeli-Nasab, B., Vessal, S., Bagheri, A., & Malekzadeh-Shafaroudi, S. (2025). Evaluation of drought-tolerant chickpea genotypes (Cicer arietinum L.) using morphophysiological and phytochemical traits. Frontiers in Plant Science, 16, 1529177. https://doi.org/10.3389/fpls.2025.1529177

Gahramanova, A. Y., Mammadova, R. N., Hasanova, T. A., Alakbarlı, G. Y., Mammadova, G. I., Asgarova, G. F. (2026). Studies on gray-brown soils with rapeseed (Brassica napus L.) as a forage crop in the Sheki region of the Greater Caucasus. SABRAO Journal of Breeding and Genetics, 58(1), 432-441. http://doi.org/10.54910/sabrao2026.58.1.40

Hasanova, G., Omarova, S., Khalilov, R., Mammadova, A., Zafar, M., Majeed, S., Ramadan, M. F., Khan, M. R., & Gul, A. (2026). Artemisia lerchiana based green synthesis of silver nanoparticles: TEM microscopy, physicochemical, and spectroscopic characterization. Microscopy Research and Technique, 89(1), 148–155. https://doi.org/10.1002/jemt.70062
Huseynova, H. Z. (2022). Vegetation of the southern part of the Caspian Coast and its nutritional value. Biosystems Diversity, 30(3), 205–212. http://doi.org/10.15421/012222
Huseynova, H. Z. (2023). New distribution areas of some species of plants on the southern part of the Caspian coast. Biosystems Diversity, 31(1), 123–130. https://doi.org/10.15421/012313
Ibrahimova, L. (2025). Modern ecological state of the soils Absheron Peninsula and ways solutions, Reliability: Theory & Applications, 7(83), 155–161.
Ibrahimova, L., Zeynalov, L., Asadov, H. (2024). Assessment of regional factors for sustainable development of agrocenoses based on gis and remote sensing. Comptes Rendus de l'Académie Bulgare des Sciences, 77(6), 849–857. https://doi.org/10.7546/CRABS.2024.06.08
Ismayil, A., Alakbar, R., Gudrat, V., Islam, R., Allahverdi, T. (2025). Soil salinization in Ujar region of Azerbaijan with index application and various methods comparison. Comptes Rendus de l'Académie Bulgare des Sciences, 78(6), 946–954. https://doi.org/10.7546/CRABS.2025.06.18
Ismayilova, A., Shukurov, S., Hasanaliyeva, L., Osmanova, S., Asgarova, G., & Hasanova, T. (2025b). Modern soil cover of natural cenoses and agrocenoses landscapes of the Kur-Araz plain. Advances in Biology & Earth Sciences, 10(2), 314-325. https://doi.org/10.62476/abes.102314
Ismayilova, M., Mammadova, R., & Mammadova, A. (2025a). Fitoindication of environmental quality utilizing the MAPLE software package. Baku State University Journal of Life Sciences & Biology, 2(1), 1-4. https://doi.org/10.30546/300045.2025.2.1.2001
Jabeen, S., Zafar, M., Ahmad, M., Ali, M. A., Elshikh, M. S., Makhkamov, T., Mamarakhimov, O., Yuldashev, A., Khaydarov, K., Gafforov, Y., Baysunov, B., Mammadova, A. O., Botirova, L., Sultana, S., Majeed, S., Rozina, Ahmad, S., Abid, A., & Rahmatov, A. (2024). Micrometer insights into Nepeta genus: Pollen micromorphology unveiled. Micron, 177, 103574. https://doi.org/10.1016/j.micron.2023.103574
Jha, U. C., Kumar, Y., & Katiyar, P. K. (2023). Capturing genetic variability in chickpea (Cicer arietinum L.) germplasm, released varieties, and advanced breeding lines under heat stress environment in North Indian climatic condition. Indian Journal of Genetics and Plant Breeding, 83(02), 270–272. https://doi.org/10.31742/ISGPB.83.2.14
Katkani, D., Babbar, A., Upadhyay, S., & Patel, V. (2022). Identification of chickpea (Cicer arietinum) breeding lines tolerant to high temperature. The Indian Journal of Agricultural Sciences, 92(11), 1391–1394. https://doi.org/10.56093/ijas.v92i11.123850
Kumar, S., Sharma, R., Rangari, S., Jha, U. C., Sahu, P. K., Paul, P. J., Gupta, S., Gangurde, S. S., & Kudapa, H. (2023). High-confidence QTLs and key genes identified using meta-QTL analysis for enhancing heat tolerance in chickpea (Cicer arietinum L.). Frontiers in Plant Science, 14, 1149025. https://doi.org/10.3389/fpls.2023.1149025
Makki, H. A., Saeed, A., Hussain, T., Rafay, T., Madnee, M., Abid, M., Allahverdi, T. H., & Nurrochmat, N. A. (2025). Enhancing soil rehabilitation in saline and sandy soils of Punjab, Pakistan using wastewater reuse and native tree species. Egyptian Journal of Soil Science, 65(4), 2039-2054. http://doi.org/10.21608/EJSS.2025.426305.2378
Mamedova, A. O. (2009). Bioindication of environmental quality based on plant mutational and modification variability. Cytology and Genetics, 43, 123–125. https://doi.org/10.3103/S009545270902008X
Mammadova, A. O., Farzaliyeva, N. M., & Mammadova, R. N. (2017). Environmental assessment of the tree plant leaves according to their physiological state and fluctuating asymmetry indices of morphological features, which widely spread in Baku. Journal of Ecology of Health & Environment, 5(1), 19-21. https://doi.org/10.18576/jehe/050103
Mammadova, A. O., & Mammadova, R. N. (2019). A study of bioindicative properties of Quercus castaneifolia C.A.Mey in natural and urbanized sites in Azerbaijan. Bulletin of Nizhnevartovsk State University, 2, 71–79. https://doi.org/10.36906/2311-4444/19-2/09
Mammadova, R. N., & Mammadova, A. O. (2020). Investigation of the possibility to use Quercus macranthera Fisch. et C.A.Mey. woody plant in the management of the sustainability of the forest ecosystem. Plant & Fungal Research, 2(2), 30–37. https://doi.org/10.29228/plantfungalres.74
Mammadova, A. O., Zafar, M., & Mammadova, R. N. (2024a). Indicative and remedial properties of Vicia faba L. Baku State University Journal of Life Sciences & Biology, 1(1), 3–12. https://doi.org/10.30546/300045.2024.1.1.3
Mammadova, A. O., Mammadova, R. N., & Ashurova, N. D. (2024b). Ecological assessment of pastures, semi-deserts and dry steppes of Azerbaijan. International Journal of Advances in Applied Sciences, 13(2), 439–446. https://doi.org/10.11591/ijaas.v13.i2.pp439-446
Mammadova, R. B., Guseynova, L. A., Bakhih, A., Abdulaliyeva, G. S., Mammadova, A. O., Mammadov, Z. M., Alizade, Sh. A., & Amrahov, N. R. (2024c). The study of genetic effects of combining ability in diallelic cotton hybrids with improved fiber traits. Advances in Biology & Earth Sciences, 9(3), 338–346. https://doi.org/10.62476/abes93338
Mammadova, R., Hasanova, T., & Aliyeva, M. (2025a). Ecological state of modern soil cover in agrocenoses of the Greater Caucasus Sheki region. Ecological Systems Modelling Collective monograph. 3, 57-73. https://doi.org/10.21303/978-9908-9706-6-0.ch3
Mammadova, R. N., Salimova, S. J., Huseynova, S. M., Mammadova, G. I., Hasanova, T. A., Rafiyeva, H. L., & Jafarova, G. A. (2025b). Plant leaves as a biogeochemical indicator of the environmental state in different regions of Azerbaijan. Comptes Rendus de l'Académie Bulgare des Sciences, 78(11), 1601–1610. https://doi.org/10.7546/CRABS.2025.11.03

Citation: Oqtay, A.M., Nazim, R.M., Adil, K.A., Mubariz, C.A., & Abdulkerim, B.J. (2026). Multıfactorıal assessment of agrobıologıcal responses of *Cıcer arıetınum* L. to hıgh-temperature stress ın agrocenoses of the Azerbaıjan Republıc. Agrobiological Records, 25, 461-470. https://doi.org/10.47278/journal.abr/2026.077

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Mammadova, A., Mammadova, R., Rzayeva, A., Mammadov, Z., & Abdullayeva, M. (2026a). The significance of bioindication in sustainable environmental management. BIO Web of Conferences, 231, 00001. https://doi.org/10.1051/bioconf/202623100001

Mammadova, G. I., Salimova, Sh. J., Jafarov, A. M., Huseynova, S. M., Isayeva, K. K., Isagova, V. G., Hasanova, T. A. (2026b). Rocky soil compositions influence on the microorganisms and vegetation at the Sheki-Zagatala Economic Region, Azerbaijan. SABRAO Journal of Breeding and Genetics, 58(3), 1407-1414. http://doi.org/10.54910/sabrao2026.58.3.43

Mammadova, G., Salimova, Sh, Aliyeva, G., Isagova, V., Hasanova, T. (2026c). Modern approaches in the study of soil bioactivity in Katekh and Garakli village (Azerbaijan) irrigated alluvial meadow and mountain forest brown soils. Bulgarian Journal of Agricultural Science, 32(2), 278–285.

Mirismayil, M. A. (2025). Activity of soil biota in the modern soil cover of Ujar, Kurdamir, and Salyan regions. Bulgarian Journal of Agricultural Science, 31(6), 1086–1091.

Mirzezadeh, R. I., Ramazanova, F. M., Hasanova, T. A., Mammadova, G. I., Asgarova, G. F. (2025). Assessment of variations caused by biological activities in the Greater Caucasus forest soils used for agriculture. SABRAO Journal of Breeding and Genetics, 57(4), 1634-1643. http://doi.org/10.54910/sabrao2025.57.4.29

Nasirova, A. (2023a). Cultivation of Malva sylvestris L. species in the Ganja-Kazakh economic region in recent years. Advances in Biology and Earth Sciences, 8(1): 114-117.

Nasirova, A. (2023b) Modern and comprehensive soil studies in grape agrocenoses in Azerbaijan. International Journal of Advances Applied Sciences, 13(2), 217-224, https://doi.org/10.11591/ijaas.v13.i2.pp217-224

Nazim, R., & Oqtay, A. (2024). Study of bio-ecological indicators of oak species in Azerbaijan. Proceedings of the Bulgarian Academy of Sciences, 77(10), 1466–1473. https://doi.org/10.7546/CRABS.2024.10.06

Palmer, A. R. & Strobeck, C. (1986). Fluctuating asymmetry: Measurement, analysis and patterns. Annual Review of Ecology and Systematics, 17, 391-421. http://dx.doi.org/10.1146/annurev.es.17.110186.002135

Samadov P. A., Mammadov Z. R., Aliyeva M. M., Rzayeva A. L., Nasirova A. I., Mammadova R.N., Mammadzade V.T., Aliyeva B.B., Sadikhova M. E. (2026). Eco-biological indicators of mountain forest soils in the Lankaran Region, Azerbaijan. SABRAO Journal of Breeding and Genetics, 58 (1) 442-452. http://doi.org/10.54910/sabrao2026.58.1.41

Verdiyeva, F. B., Abdullayeva, R. K., Ismayilzadeh, N. N., Fatdayeva, A. K., Mammadova, G. I., Hasanova, L. U., Asgarova, G. F., & Hasanova, T. A. (2026). Biosynthesis of seeds and bioecological parameters of gray-meadow soils by remote sensing (Republic of Azerbaijan) under wheat crops. International Journal of Agriculture and Biosciences, 15(4), 126-137. https://doi.org/10.47278/journal.ijab/2026.075